# EGYPTIAN IRRIGATION

THIRD EDITION

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# EGYPTIAN IRRIGATION

VOLUME I

# EGYPTIAN IRRIGATION

BY

SIR W. WILLCOCKS, K.C.M.G., F.R.G.S.

FORMERLY ADVISER TO THE MINISTRY OF PUBLIC WORKS, CONSTANTINOPLE,
MANAGING DIRECTOR OF THE DAIRA SANIA COMPANY, AND
DIRECTOR-GENERAL OF RESERVOIR STUDIES, EGYPT;
MEMBER OF THE INSTITUT-ÉGYPTIEN, CAIRO:

AND

J. I. CRAIG, M.A. (EDIN.), B.A. (CANTAB.), F.R.S.E., F.R.MET.S.

MEMBER OF THE CIRCOLO MATEMATICO DI PALERMO; LATE WATSON FELLOW (EDIN.);
DIRECTOR COMPUTATION OFFICE, DIRECTOR METEOROLOGICAL SECTION, EGYPTIAN
SURVEY DEPARTMENT; NOW CONTROLLER, DEPARTMENT OF GENERAL STATISTICS
MEMBER OF THE INSTITUT-ÉGYPTIEN, CAIRO

WITH AN INTRODUCTION BY

SIR HANBURY BROWN, K.C.M.G.

M.INST.C.E. (LATE R.E.)

FORMERLY INSPECTOR GENERAL OF IRRIGATION, EGYPT

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"O thou River, who did'st bring forth all things,
When the great gods dug thee out,
They set prosperity upon thy banks."
—*Ancient Babylonian Hymn*

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Dedicated

TO

THE RIGHT HON. SIR ERNEST CASSEL, G.C.B., G.C.M.G., G.C.V.O.

*To whom Egypt is indebted for the funds with which the Aswan Dam and Assiut Barrage were begun, for the National and Agricultural Banks of Egypt, and for the opportunities of purchase of the Daira Sania lands by the fellahin of the country on conditions such as Egypt had never seen before. His dictum that the Board of Directors of a Land Company owed duties to its neighbours as well as to its shareholders, might be acted on with advantage in every country of the world.*

# PREFACE.

THE first edition of *Egyptian Irrigation* was published in 1889, and the second in 1899. The latter has been out of print for some years, and when, at the end of 1911, the question of a third edition arose, Sir William Willcocks invited Mr J. I. Craig to join him in writing it.

The second edition was dedicated to H.E. the late Nubar Pasha, G.C.S.I., G.C.M.G., the author of the well-known saying that "the Egyptian question was the Irrigation question." Without irrigation there could be no Egyptian people, certainly no civilisation in Egypt. The influence of irrigation pervades Egyptian economics, politics, social life, agriculture, legislation, and even religion. So far-reaching are these influences that the authors have not hesitated to draw freely on the works and writings of others—each a specialist in his own line—so that much of the labour of composition has consisted of pure compilation. The material is so abundant that, in making a selection from it, some papers of importance may have been overlooked or underestimated; but it is hoped that the result is to set forth, with a minimum of error of omission and commission, a full account of Egyptian irrigation at the beginning of the second decade of this century.

Although the plural has been used throughout in the text, Mr Craig, as an official of the Egyptian Government, expresses no criticism of the work of his colleagues or the plans of the Government. Such criticisms are from the pen of Sir William Willcocks alone.

A work of this nature must necessarily contain a vast body of facts and figures. Reference to these, however, will be facilitated by the system of triple indexing adopted, whereby a list of contents with numbered paragraphs is given at the beginning of each volume, the number and subject of each paragraph is indicated at the top of each page, and a full index is provided at the end of the second volume.

The fullest information obtainable of the Nile and its tributaries has been given. This has been done purposely, as the problems connected with the Upper Nile cover some of the most interesting hydraulic questions in the world, and those who are desirous of studying them will find ample material to hand.

The preservation of uniformity in the transliteration of Arabic words between the text and the plates has been found impracticable, but it is believed that no confusion will thereby arise.

In using the work of others, reference to the authority has been quoted, but advantage is taken of this opportunity to acknowledge the willingness with which permission to make use of the assistance of the members of their staff has been accorded by Colonel Lord Edward Cecil, D.S.O., Financial Adviser; Mr C. E. Dupuis, late Adviser for Public Works; Mr M. MacDonald, C.M.G., Under Secretary to the Public Works Ministry; Mr E. M. Dowson, Director-General of the Survey Department; Mr G. Dudgeon, Director-General of the Agricultural Department; and Mr P. M. Tottenham, Inspector-General of the Sudan Irrigation Service.

To H.E. Sir Reginald Wingate, G.C.B., Governor-General of the Sudan, thanks are due for permission to consult his officers and for ample opportunities of inspection and investigation of the Nile and its tributaries.

The majority of the plates and figures have been extracted from the publications of the Public Works Ministry and Survey Department.

The late Lieutenant-Colonel Ross, C.M.G., the first Inspector-General of Irrigation, wrote the Introduction to the first edition of this work, and Sir Hanbury Brown, K.C.M.G., wrote the Introduction to the second. Sir Hanbury has honoured the book by contributing the Introduction to this third edition.

CAIRO, *September* 1913.

## CORRIGENDA.

Page 121. Line 27 from the top, for *width* read *widths.*

Page 364. Line 3 from the bottom, for the figures in the text read *91·40, 92·08, 91·68, 91·72, 91·52.*

Page 770. Line 12 from the top, for *acre* read *area.*

To face p. xvi. Willcocks and Craig, *Egyptian Irrigation.*

# INTRODUCTION.

By Sir HANBURY BROWN, K.C.M.G.
M.Inst.C.E., Late R.E.
FORMERLY INSPECTOR-GENERAL OF IRRIGATION, EGYPT.

More than fourteen years after Sir William Willcocks paid me the high compliment of asking me to write the Introduction to the second edition of *Egyptian Irrigation*, he has again honoured me by an invitation to do the same for the third edition. The work has grown to two volumes, and there are now two authors to introduce. No such introduction may be necessary for those who are familiar with the recent history of Egypt and the reformation and achievements of its Irrigation Department. But *Egyptian Irrigation* has its lessons for other countries besides Egypt and for generations yet to come; and for their sakes it is well to make use of this Introduction for setting forth what qualifications the authors have for their task. Where names are mentioned present titles are used in this Introduction.

Sir William Willcocks, after distinguishing himself beyond his fellows as a student at the Thomason Civil Engineering College, Roorkee, and passing out brilliantly, made his mark in the Irrigation Department of the North-West Provinces of India, and gained much useful experience during eleven years' service in India. After the landslip of Naini Tal in 1880, he designed and built the protective works necessitated by that catastrophe; and during the last two years of his service in India, as resident engineer in charge of the work, he built the greater part of the Betwa Dam. From this work he went direct to Egypt at the end of 1883, leaving India, his birthplace, for the first time in his life. He was one of the pioneers in the work of causing order to evolve out of the chaos in which Sir Colin Scott-Moncrieff found the Irrigation Service of Egypt. During the fifteen years that followed, Sir William Willcocks, like Joseph of old, went throughout all the land of Egypt, and gained a comprehensive knowledge of the country and of the condition of its irrigation and agriculture. He was the first to discover that the Delta Barrage was wrongly classed with the incurables, and to demonstrate that its shattered constitution could be restored to a sufficiently sound state of health to enable it to do its

appointed work—a revelation that has had in the sequel beneficial results to Egypt of the first magnitude. As Inspector of Irrigation of the Central Provinces of the Delta, his energy and enthusiasm astonished all with whom he had to do. And it was while he was an Inspector that he took the lead in introducing and carrying out the experiments which paved the way for the abolition of the corvée—a reform also of the first magnitude. During the exceptionally low flood of 1888 he had the good fortune to be told off to accompany and advise the Minister of Public Works on a special mission to Upper Egypt, undertaken to consider measures for meeting the difficulties of the situation ; and it was in consequence of the successful results of the mission that he became the hero of the account, given in Milner's *England in Egypt*, of an English irrigation officer being invited to join and taking part in a Mohammedan thanksgiving service in a mosque at Tahta in Upper Egypt. This mission gave him a clear insight into the conditions of basin irrigation.

Later on, as Director-General of Reservoirs, he conducted the studies which led to the decision to make a reservoir above the First Cataract ; and he drew up the designs and estimates of the Aswan Dam and the Assiut Barrage—projects which may well be described also of the first magnitude.

His next task was that of ascertaining the rental value of all land in Egypt, with the object of obtaining figures on which a re-assessment of the Land Tax could be based—a mission that could not fail to teach him much about the country, its strong and weak points. This task accomplished, he then became Manager of the Cairo Waterworks and, while holding that appointment, prepared a drainage project for Cairo on behalf of the Waterworks Company. After that, he was appointed Managing Director of the Daira Sania Company by Sir Ernest Cassel, and effected the sale of land and sugar factories to a total amount of £11,000,000. Afterwards he made a journey up the Nile to the equator, and wrote a paper containing his observations and proposals as the outcome of his expedition. Lastly, from 1908 to 1911, he acted as Adviser to the Turkish Government for Mesopotamia, and prepared projects for irrigating 3,000,000 acres and controlling the Euphrates and Tigris.

Such an environment of work, acting on natural ability to assimilate knowledge and to profit by experience, has produced in Sir William Willcocks an expert of exceptional authority on the subject of Egyptian Irrigation.

His collaborator in this new edition—Mr J. I. Craig—has likewise high qualifications for authorship, though of a different order. He is a distinguished mathematician and meteorologist. He gave much assistance to Sir William Garstin on his journey from Lake Albert to Khartoum, and prepared the discharge tables for his *Report upon the Basin of the Upper Nile.* During the past twelve years he has been to Uganda, up the Blue

Nile to Roseires, to Abyssinia, and three times up the Albert Nile, besides having been engaged on seepage investigations between Khartoum and Wadi Halfa. He has been Surveyor, Meteorologist, and Director of Hydrography to the Survey Department of Egypt, and is now Controller of General Statistics to the Egyptian Government. Sir William Willcocks, by inviting his co-operation, has shown his good judgment, and has thereby secured for this third edition an enhanced value as a scientific work.

Knowledge of the Nile and of all matters connected with it has increased to a remarkable extent since the second edition of *Egyptian Irrigation* was published. The very first chapter of this third edition is full of new information that was not available for the earlier publication. Perhaps the section of this chapter which deals with the movement of ground water is the most interesting to an irrigation engineer from a practical point of view, as bearing directly on problems of irrigation and drainage. Again, in CHAPTER III., which has for its heading "The Nile in Detail," will be found described, as never before, all parts of the river system which belong to the valley of the Nile from its sources to the sea. Compare the information therein collected with what was known when the first, or even the second, edition of this work was published, and it will be realised what a long stride knowledge has taken.

And not only has knowledge increased, but Egypt has added to its possessions important works of irrigation which are themselves wealth producers. In the Introduction to the second edition I related how, in 1883 and 1884, when Sir Colin Scott-Moncrieff was organising the Irrigation Department, the first thing his staff had to do was to arrest decay and prevent things going from bad to worse, at the minimum expenditure possible, and with no records of past experience to guide them. As a further step in advance what was bad had to be made good; and the Western practice of repairing existing works was one of the first novelties introduced to take the place of the Eastern practice of letting works, once constructed, take care of themselves. Ruins of earthworks and masonry buildings were restored and made to perform their duties; hopeless wrecks of native inspectors and chief engineers, unfit for the open sea of profitable service, were towed into port and left there. The native officials of the subordinate staff who survived the stress of reform learnt that they were paid for work; and they also were made to perform their duties and move about their districts—another startling novelty. Then, when fuller experience had been gained by the new reformers, came the period of remodelling and making crooked ways straight, both materially and morally: defects (by no means all) in the system of canals and drains were removed, the cross-section and grading of canals and banks were adapted to their objects, and extensive alterations to masonry works were

carried out to make them work with more efficiency and less expenditure of human labour. And, at last, when the Nile supply had been made to do the maximum work that could be got out of it, and the beneficial effects of repairs of works, remodelling of canals, perfecting of the means of regulation, and just distribution of water had been made evident in increased crops and general prosperity, and there seemed to be little for the matured experience of the reformed Department to operate upon within the limits imposed by the ordinary Budget allotments, a new prospect of development was opened. Funds were found for extending the drainage system of Lower Egypt, and, after hope deferred, for endowing Egypt with a storage reservoir and for building, besides, other works of first importance. Since 1899—the date on the title-page of the second edition—there have been built on the Nile itself and brought into operation the Aswan Dam, the Assiut, Zifta and Esna Barrages, and the weirs below the Delta Barrage; and, as subsidiary to these, a large number of regulating works of distribution in both Upper and Lower Egypt.

The construction of these works has been attended, or followed, by some notable results. During the ten years following the publication of the second edition of *Egyptian Irrigation*, the total value of the imports of Egypt more than doubled itself, rising from £(E.)11,000,000 to over £(E.)22,000,000, while the exports increased in value from £(E.)13,000,000 to £(E.)24,000,000. During the same period the revenue of the country increased from £(E.)11,500,000 to £(E.)16,000,000. Irrigation claims a large share of the credit for the progress to which these figures testify. Egyptian Irrigation is, therefore, a subject which all must study who wish to understand the causes of Egypt's recovery from a state of bankruptcy to wealth.

As I pointed out in the Introduction to the second edition, this book is not the presentment of one man's view, inasmuch as the opinions of many experts find expression therein in their own words, even when they are opposed to those held by the authors. Take as an instance of this treatment the subject of Land Reclamation in CHAPTER VIII. No fewer than ten different agricultural or land experts and managers of Land Companies are quoted for the edification of the reader. In one case, it seems to me, this impartiality has been carried to an extreme, as what appears to be a misleading view, supported by the authority of an acknowledged expert, is left unquestioned and without comment for fully four chapters. In CHAPTER IV. Colonel Ross is quoted as advocating the practice of Arab engineers regarding the position and direction of a canal offtake from the Nile. In CHAPTER IX. Mr P. Claxton is quoted as holding very different views and, to my thinking, sound ones. Mr Claxton's conclusions are supported by the case of the Abu Bagara Canal in Middle Egypt, which,

so far as I know, was almost the only canal in Egypt which did not silt. Its offtake was situated a short distance up a creek at a point which agrees with Mr Claxton's description of the ideal one. On the other hand, the example of the Kasra Canal, cited by Colonel Ross, proves—if it proves anything—how wrong the Arab practice was. The head took off the deep water where the current was strong, in a direction making an acute angle with the axis of the river. So unfavourable was this arrangement that a succession of offtake channels had been dug from time to time, as the silting was so heavy that the spoil banks at length grew to such a height that it was more economical to dig a new take-off than to continue lifting the silt over the accumulation of previous years' clearings. On pages 18 and 19 of my book *Irrigation* I called attention to the practice of the Arab engineers as one not to be imitated.

CHAPTER VIII. deals with the important question of drainage as well as land reclamation. The difference of opinion I had with Sir William Willcocks in the second edition, concerning means for the disposal of excess water, no longer exists. We are now agreed that the escape water of canals, the water of surface washings, and (where levels admit) the surface drainage also, should be economically got rid of by gravitation flow in "escape-drains"; and that the infiltration water or drainage of the subsoil, below the level at which gravitation can efficiently dispose of it, should be conducted in special drainage channels to pumps, which would lift the water into the main escape-drains. As regards the pumps, there would seem to be a difference of opinion between the authors of this book and the Ferrara engineers on the one side and the technical advisers of the Egyptian Government on the other. The former advocate a comparatively large number of small pumps to deal with the drainage in place of a few large pumping stations such as are contemplated in the officially accepted drainage scheme for Lower Egypt. Efficiency is most perfectly obtained and waste of power best avoided by getting close to the work. Whether the economy of running one large pumping station instead of many smaller ones should be allowed to outweigh these and other considerations depends upon circumstances. Presumably those who decide these matters in Egypt have thoroughly studied the question from all points of view before coming to a decision of such importance to the country. Perhaps the consideration, the importance of which is emphasised by the authors, demanding most attention is the need of securing a plentiful supply of "red" water during the flood season to all parts of the cultivated area. Any irrigation or drainage scheme for the Delta which does not make provision for such a supply is defective in a most essential particular. More especially is the restorative effect of flood water necessary to the Delta lands since overcropping with such an exhausting plant as cotton has become common.

In CHAPTER VII. will be found a quotation from Sir William Willcocks' lecture of 11th December 1911, entitled *A Ten-Million Kantar Cotton Crop*, contesting the view that no inconsiderable part of the heavy drop in the yield per acre of cotton, from $5\frac{1}{2}$ kantars to $4\frac{1}{2}$ kantars, has been due to the large area of inferior land which has been put under cotton of recent years. It seems to me the view he contests is a quite reasonable one. The areas reclaimed may be in better condition than used to be the case; but still, when first reclaimed, I imagine their yield is well below the average yield of the whole Delta. I do not wish to dispute the statement that "the poor lands are better, the rich lands are worse," but merely to present some figures to show that it is probable that the deficient yield of lands when first reclaimed has affected the average yield. The following table gives actual figures, in round numbers as far as areas are concerned:—

| Year. | Area planted. Cotton. | Yield per Acre. | Increase of Area. | Rate of Increase of Area, per cent. |
|---|---|---|---|---|
| 1895 | 1,000,000 | 5·27 | | |
| 1901 | 1,250,000 | 5·10 | 250,000 | 25 |
| 1906 | 1,500,000 | 4·61 | 250,000 | 20 |
| 1911 | 1,710,000 | 4·34 | 210,000 | 14 |

Assuming that the better lands are the first to be reclaimed, the yield of the successive reclamations will be less and less. If the first increase of area yields (as a supposition) at the rate of 4 kantars an acre, the second $2\frac{3}{4}$ kantars, and the remaining 210,000 acres $2\frac{1}{4}$ kantars, the average yield will work out as above with the original yield of the area of 1895 unchanged at 5·27 kantars. The figures assumed as representing the yield of the added areas are imaginary and are probably below the true figures. But I think the above figures show that it is reasonable to believe that some, at least, of the depreciation in average yield is due to the fact that the yield of newly reclaimed lands, being below the average of the older cultivation, lowers the general average.

There are so many influences affecting the yield of cotton that it is difficult to decide which has predominated in any particular year. In 1909, when the total yield of the crop was only 5 million kantars, probably several causes combined to produce such a lamentable result. April storms and September fogs, cotton worms and boll worms, too close sowing, inferior seed, over-cropping, over-watering, high subsoil water, infiltration from the river in flood and inefficient drainage are all causes which affect the crop adversely. The three last-named causes are matters which concern the Irrigation Department. The study of the movement of ground water, to be found in CHAPTER I., should be helpful in devising means for dealing with the evil of high subsoil water. As a remedy in the

southern Delta, lift irrigation in summer is recommended in CHAPTER VII. It is there stated that "these lands to-day with half their area under cotton do not give so good a yield as they did in the old days of lift irrigation when one-third the area only was under cotton, and the spring level was 2 metres lower than it is to-day." The conclusion drawn by the authors is that flush irrigation is to blame and that lift irrigation is the remedy. But it must be observed that the sentence quoted reveals the fact that over-cropping is now the general custom. May it not then be the chief cause of the mischief? If it is, there is this further argument in favour of a return to lift irrigation—that the labour and expense of lifting the water would discourage the planting of so large a proportion of the cultivated area, and over-cropping would receive a check.

At the end of CHAPTER XII. the authors enunciate their proposals for the further husbanding of the Nile waters for the use of Egypt and the Sudan. Among their proposals there is no mention of any project for storing water in Lake Albert. But its place is taken by other schemes. The Gebel Auli and Gebelein Reservoir projects are new schemes which find no mention in Sir William Garstin's *Report on the Basin of the Upper Nile*, published in 1904. The waters of these White Nile reservoirs would be stored downstream of the Sudd region, and would not have to pass the swamps that levy such heavy toll on all streams that traverse them. The White Nile reservoirs project has therefore this consideration to recommend it as a preferable scheme to all others which contemplate storage of waters above the region of the sudds.

In CHAPTER XIII. will be found some free criticisms of the developed Aswan Dam and the method of using the reservoir water. Fortunately for Egypt's peace of mind it is admitted that the dam, as it stands, is trustworthy, being quite capable of safely bearing the strain that the raised level of the reservoir has brought to bear upon it. In paragraph 138 the bold proposal is made to increase Egypt's summer water supply still further by building a new dam on the downstream side of the talus of the existing dam to hold up water to R.L. 120·00 metres, utilising the present talus as an upstream apron to the new work. Presumably all of the existing dam above talus level would be scrapped. The estimated cost of this proposed work is £4,000,000. The authors of *Egyptian Irrigation* are not wanting in boldness of conception, nor is there anything lacking to them in the courage of their opinions. But the pace is too hot for me. As an irrigation engineer on active service I belong to the end of the nineteenth century, when Inspectors of Irrigation rode donkeys whose patience and deliberation gave them time to think. Motor-cars now regulate the pace, and it would seem that the authors of *Egyptian Irrigation* have been

infected by the spirit of haste. To propose to dismiss the present dam from the Irrigation Service before it has had time to fully develop its usefulness, in order to put in its place a successor, however promising, seems to me to be, at least, premature.

So far as the criticisms of the existing dam and the replies thereto are concerned, clouds of statements with positive and negative charges appear to be in the air, and until they have cleared away and facts become plainly visible, it is best to postpone any observations. Whether the criticisms are justified or not, I gather that the authors claim that, at least, they are valuable as an antidote to "perpetual incense and praise."

But whatever value the criticisms contained in CHAPTER XIII. may have, there cannot be two opinions concerning the value of the book as a whole. Any country which is dependent on an artificial supply of water for the raising of its crops, may consider itself fortunate if it possesses a work, treating of its irrigation, so thorough, scientific, and complete as this third edition of *Egyptian Irrigation.* Not only is it a trustworthy guide and instructor for any engineer entering the Irrigation Service of Egypt, but there is enough matter between its covers to educate any student of Irrigation in almost all that he needs to know, save only what experience alone can teach and what is peculiar to any particular country. Its formidable bulk is due to the merit that it has of quoting the passages which the authors consider illuminate the subject, instead of referring the reader to some other work which he may not have the means of consulting. The closing words of Colonel Ross's Introduction to the first edition may be repeated now with fuller emphasis, to the effect that "this book takes away the reproach from Egypt that the outer world can never find any facts concerning the supply and distribution of the waters of the Nile."

HANBURY BROWN.

NEWLANDS,
*21st August* 1913.

# EGYPTIAN IRRIGATION.

## CHAPTER I.

## *GENERAL.*

1. Geology of the Nile Valley south of Khartoum.—2. Geology of the Nile Valley in the Northern Sudan.—3. Geology of the Nile Valley in Egypt.—4. Geology of the Fayum and the Wadi Rayan.—5. Meteorology of Egypt.—6. Meteorology of the Upper Basin of the Nile.—7. Soil of Egypt.—8. Soil of the Sudan.—9. Nile Water.—10. Ground Water and Drainage Water.—11. Evaporation and Absorption.—12. Movements of Ground Water.—13. Areas of Land under Basins and perennially irrigated.—14. Principal Crops, Trees, and Animals.—15. Land Proprietors.—16. Population.—17. Railways, Roads, and Navigation.—18. Imports and Exports.—19. Revenue, Expenditure, and Debt.

1. **Geology of the Nile Valley south of Khartoum.**—The first four paragraphs of this book have been kindly written for us by Dr W. F. Hume, Director of the Geological Survey of Egypt.

The tributaries of the White Nile take their rise in the upland plateaux of Uganda, which are composed of a series of gneisses and crystalline schists forming the oldest rocks known in Africa. These are, however, to a large extent, hidden beneath a thick covering of ferruginous laterite derived from their decomposition, under the conditions of high temperature and heavy rains prevalent in the tropics. Farther to the north, they are exposed in the Lado Enclave and in Kordofan, and also form the foundation rocks of the Abyssinian hill-system, thence extending northward as the watershed ranges separating the Nile basin from the drainage area of the Red Sea.

Associated with, and intruded into, these ancient metamorphic rocks is a series of intrusive granites, diorites, etc., forming dykes and veins in them. These igneous masses attain increasing importance in the Sudan, to the west appearing in Kordofan, and rising from under the cotton soil to the east of Khartoum. In the Red Sea Hills they attain an exceptional development, where they form some of the finest hill-masses bordering the Red Sea on the west.

These are the essential rocks determining the structure of the region in which the southern feeders of the Nile have their origin; but the distribution of these feeders, and especially of the great lakes scattered along their course, has been regarded as due to earth-movements which have not only led to the formation of the great basin of Lake Victoria, but also to the two remarkable narrow depressions or "Rift" valleys that seam the plateaux of Central Africa. These commence at Lake Nyassa and bifurcate at its northern end, the western branch being of special

interest as determining the sources and trend of the Semliki, as also the positions of the Albert-Edward and Albert Lakes.

North of Nimulé (about 3° 45′ N.) the river, descending through a narrow ravine to a series of rapids, enters the plain tract at Gondokoro, and the geological features are obscured by the rich vegetation of the Southern Sudan. Only in a few localities are the deeper-seated rocks exposed on the White Nile, Gebel Ahmed Agha being basaltic, and the hills of Gebelein and Arushkol (the latter north-west of Dueim) granitic in their nature. Most of the original land-surface is hidden beneath a thick covering of cotton soil, derived from the materials brought down by the torrential rains from the Abyssinian hills. At Tura, 80 kilometres north of Dueim, on the east bank of the White Nile, this formation is underlain by a grey, sandy clay containing quartz pebbles and numerous very fragmentary remains, which have been recognised as belonging to a siluroid and to Polypterus, both fishes at present living in the Nile. Associated with these was the broken canine tooth of an extinct giraffoid animal related to Samotherium and Sivatherium. Further study may indicate that these beds are of more than local importance.

The reduction in the velocity of the stream when it issues from the hill-country of Central Africa, taken in conjunction with the high temperatures prevalent in the Southern Sudan, has encouraged the growth of a dense vegetation in the lagoons. Swept thence by the currents or winds into the river, it forms the sudds, blocks the narrow channels, and, acting as a filter, checks the transport of sediment northward. In consequence, the coarse quartz-grains and heavier minerals derived from the granites and gneisses of Uganda, etc., form a relatively small portion of the material contributed by the White Nile to Egyptian soil.

The Blue Nile and the Atbara, on the other hand, descend directly from the steep slopes of the Abyssinian highlands, which are composed of vast thicknesses of eruptive rocks resting on a basis of gneiss. These volcanic materials, especially those of basic character (such as the basalts, which are among the principal rock constituents of Abyssinia), are, when decomposed, producers of some of the most fertile soils on the face of the earth. During the heavy rainstorms of the early summer, every torrent descending to the lower level bears a heavy load of this sediment, which is partly spread over the Sudan plains and partly carried by the great tributary streams to the Nile.

The decomposition of the lime-felspars which form one of the main constituents of these rocks supplies the clayey material and the lime, the latter amounting to as much as 5 per cent. at Roseires, while the calcium phosphate present as crystals of apatite yields a ready supply of phosphoric acid. This abundance of carbonate of lime in the Blue Nile waters leads to the development of calcareous concretions or even impure limestones on the border of the Blue Nile east of Khartoum. These beds constitute an important economic factor, as they supply the lime necessary for building operations at that town.

The former great volcanic eruptions in Abyssinia have originated the rich silt, which, carried in the red water of the Nile, constitutes the most important fertilising contribution to Egypt's soil.

After leaving the volcanic hills, the Blue Nile passes through a granitic region, of which Roseires may be regarded as the centre, and whence the river derives a part of the quartz sand which forms so conspicuous a feature in its lower reaches. Before reaching Khartoum, it enters the wide plains where the Nubian sandstone

forms the essential rock formation, overlying gneiss and granite alike, and spreading far over the Central and Northern Sudan, except where hidden beneath a covering of cotton soil. This great formation marks the advance of the sea over North-east Africa during the Cretaceous period, that is, at the time when the White Chalk was being formed in the sea which then covered Southern England and North France.

2. **Geology of the Nile Valley in the Northern Sudan.**—At Omdurman, where the Blue and White Niles meet, the stream formed by their union flows on between sandstone plains to the Sixth Cataract. One of the most remarkable physical features in the Northern Sudan is the great S-shaped curve, which extends over six degrees of latitude, and more than three degrees of longitude. The lack of geological knowledge regarding the neighbouring deserts renders it impossible to give a conclusive explanation of its origin. In the valley itself there is a triple repetition of areas where gneisses and granites appear from under the Nubian sandstone which forms the main surface rock of the country. Each of these regions of metamorphic (gneisses) and igneous rocks (granites) is characterised by the presence of cataracts. In these the waters, hemmed between islands and rugged banks of igneous rocks, and with steeply sloping channels, form rapid after rapid between the small islets which partially bar the stream. Their presence is due to the variation in mineral complexity and hardness presented by the dykes of granite or dolerite which have been intruded into softer gneisses and schists.

The Sixth (Shabluka) Cataract is in the main a ravine cut through a thick series of columnar felsites and ancient volcanic rocks rising in the midst of a lower-lying region of gneiss seamed by harder granitic veins; in the Fourth and Third Cataracts the hard granite penetrating the softer gneisses and schists forms impediments to the free flow of the stream. In the long stretch of broken water which extends with but few breaks from the Third to the Second Cataract a similar complex geological structure gives rise not only to hard bands (granite) in soft rocks (schists, etc.), traversing the river at right or acute angles, but also to soft veins in hard rock, trending parallel to the river's direction. A typical example of this is the Bab-el-Kebir, the finest rapid near Wadi Halfa, which, during the flood season a foaming mass of water restricted to a narrow channel, in winter is an almost dry ravine filled with boulders. The bounding walls consist of one of the most resistent rocks, a gabbro, while a softer variety, a porphyrite, has been intruded into it, determining the position of the rapid by its easy erosion.

Between these regions of complex igneous and metamorphic constituents are long stretches of Nubian sandstone country; the duplicate character of the Nile (cataracts and smooth stretches) being thus directly due to the varying geological structure.

From the point of view of reservoir construction the cataract areas south of Aswan have all failed in essential particulars to satisfy the demands. In general the rapid change of level in the cataract regions makes the possible reservoir contents too small. Only in the Fourth Cataract is there any similarity in rock structure to the Aswan dam area, but close examination showed that the granites of this region were far inferior in texture to the well-known Aswan variety, while softer dykes of diabase and porphyrite seamed them.

3. **Geology of the Nile Valley in Egypt.**—The ravine of the Nile between Wadi Halfa and Aswan, bounded by cliffs of Nubian sandstone, and terminated by the rocky ravine gorge of Kalabsha and the complicated island

system of the First Cataract, belongs strictly to the geological facies developed in the North Sudan, the rocks present at the Aswan dam being highly crushed and faulted igneous rocks. The most prominent of these, and the only one visible before excavation was begun, is the well-known coarse-grained red granite which had suffered least from crushing and weathering. This granite alternates irregularly with more basic rock, mainly mica-diabases, which, on account of their structure and mineral constitution, have undergone great decomposition under the combined agency of crushing and water-action; they often form schistose masses soft enough to be taken out with a pick. The presence of these readily denuded materials has determined the position of the principal channels, whereas the granite between them stands out as islands.

Expressed in its simplest form, Egypt consists for the greater part of sedimentary rocks of Cretaceous and Eocene age, attaining from 1000 to 2000 metres in thickness, and contemporaneous with the period during which the White Chalk and London Clay were being deposited in England. The ancient granitic rocks appear from under these strata on the east, forming the Red Sea Hills.

The main portion of Egypt is geologically an extremely flat syncline, or basin-shaped area of oval form, truncated at the northern end by the Mediterranean Sea, the strata dipping gently from south, west, and east towards a central, north-west, and south-east axis. In consequence, the outcrops of the various formations are themselves roughly U- or V-shaped, with their apex pointing southward.

Egypt is geologically divisible into a series of areas characterised by the rocks which are dominant in them. Nearly two-thirds of the region is composed of *limestones* which, exposed to the action of the sand blast and arid desert conditions, give rise to the high plateau desert extending from Cairo to Esna, on the one hand, and from west of Baharia and Farafra Oases to Wadi Kena on the other. Fringing the limestones, and underlying them, is a band in which white chalk or thin-bedded shales are the conspicuous features, the fossils they contain showing them to have been formed during the Cretaceous period, while from below them, to east, south, and south-west, rise sandstones, which by their easy denudation have determined the presence of wide depressions, such as Wadi Kena, and the oases of Kharga, Dakhla, and Baharia.

These sandstones in their turn rest upon the fundamental rocks of North-east Africa, consisting of granites, schists, and ancient volcanic rocks. The latter form the mountain chains bordering the Red Sea, and there is little doubt underlie the limestones and sandstones throughout Egypt. They reappear in isolated localities from under the sandstones, especially in the Cataract regions, also near Dungul Oasis, and in the Abu Bajan Hills, at the southern end of Kharga Oasis. Their most important occurrence in the Nile Valley is, as already stated, at the First Cataract, where, in addition to forming the foundation of the dam, they have supplied the monumental granite so largely used by the ancient Egyptians. Owing to the general inclination of the dip of the strata being northward, and nearly twenty times as great as the slope of the valley, the river passes in succession from the older to the younger strata, each region traversed being characterised by features of importance to the agriculturist and irrigation engineer.

North of Aswan the river enters the Nubian sandstone formation, which consists of an alternation of sandstones and clays. The Aswan clays are largely employed for bricks, pottery, and other economic purposes, being sent to every part

of Egypt, while the sandstone, though relatively a soft rock, was largely quarried by the ancient Egyptians at Gertass, south of Aswan, Silsila, and Serraj, on account of the ease in working it and its facility for taking colours. All the most important temples from Upper Egypt to the Northern Sudan are built of this material. From an irrigation point of view the sandstone is also of interest because of its ready absorptive power, much of the river water passing into it during the period of flood, and in some localities between Aswan and Wadi Halfa returning as springs at low Nile.

At Serraj, and still more markedly in the Kom Ombo plain, quartz gravels or sand and sandy clay deposits are present at 25 metres above the highest flood level of to-day. The Kom Ombo plain has been called into existence by an extensive fault, which is traceable along its northern edge. The white limestones which overlie the sandstones further north near Esna have been let down against the sandstones and are still present at Ragama and to the east of the railway. It has also determined the long sandstone ridge of Silsila, which probably helped to pond back the waters descending from the Red Sea Hills through Wadi Shait, there being apparently no connection with the Abyssinian Nile at the period when the lake beds were being formed. Gravel terraces of Red Sea rock fragment form a conspicuous feature in the plain. The main drainage of the area was through the broad channel 1500 metres wide, lying to the east of the Silsila ridge, which has been filled to a depth of 15 metres. The present river channel is of much later date.

A broad depression at Edfu is also noticeable, but contains no conspicuous gravel deposits. North of Mahamid, at Sebaia, the river enters a region where the alternation of sandstones and clays is replaced by one of limestone and thin-bedded shales. The change is marked by a limestone rich in phosphate of lime (due to the abundance of fish teeth, vertebræ, and coprolites present in the bed) which has been traced from Dakhla Oasis in the west to the Red Sea, always in the same geological position at the junction of the sandstone clay and the limestone shale series. This layer is now being worked at Sebaia, and also at Wadi Safaja on the Red Sea, the content of tricalcic phosphate in some beds rising to over 70 per cent.

The thin shales which overlie them, alternating with white chalky limestones, form the low broken country which extends from near Esna to north of Kena, and the base of the isolated precipitous hills of Eocene limestone which rise as isolated outliers to the east of the Nile Valley above Matana, in Gebels Sarrag, Abu Had, etc. They are also of agricultural interest as containing the nitrates which, under the name of *Marog*, are collected by the natives and spread over the fields as fertilisers. The average percentage of nitrate noted in the clays is 8·4, the maximum recorded being about 34 per cent.

These shales also form the basis of the most important pottery industry in Egypt, being specially suitable for the porous ware produced in large quantities at Taramsa and Kena.

From their fossil contents their age has been determined as corresponding to the uppermost white chalk (Upper Cretaceous) developed in Denmark, from whence they are described as being of Danian age. The remarkable bends of the river between Luxor and Naga Hammadi may be connected with folds which have been proved to exist in the neighbouring desert to the east. The river has cut its path where the softer shales are exposed.

The precipitous scarp of the "Sin el Kidab," which trends parallel to the Nile Valley from Dungul Oasis to Esna, lying some 45 kilometres west of it, is approached by the river near Esna, and from thence onward forms the bold scarp dominating the valley as far as Kena. This scarp is formed by the massive and flint-banded limestones of the Eocene series, corresponding in age to the rocks on which London and Paris are built and, like these Londinian and Parisian strata, containing species of the fossil Nummulites, which is one of the most characteristic genera in the Eocene strata. These heavy limestone masses resting on the softer Cretaceous clays between Luxor and Kena have given rise to a very characteristic type of scenery, the broken foothills of mixed white limestones, green shales, and flint-banded strata lying at the foot of the higher scarps, and giving rise to the desolate aspect of the desert bordering the railway between Shagab and Matana.

This portion of the Nile Valley is also marked by the great development of gravel terraces which border the valley, and are mainly composed of limestone pebbles. Their rounded nature indicates the great activity of torrents, which obtained their load from the breaking down of the limestone ranges that now rise abruptly as thin knife-edge ridges from among these pebble-strewn plateaux. The extent of this activity is shown by the abundance of igneous pebbles in the gravels near Kena, which must have travelled a minimum distance of 60 kilometres before they reached their present position. At Naga Hammadi, the river leaves the region of the clays and enters the long ravine, which, bounded on both sides by precipitous scarps of Eocene limestone, 300 metres high, extends to beyond Assiut. This remarkable feature has been compared with the rift-valleys attributed to fault-action in Sinai and Central Africa, but as such faults as have been observed do not fit into any scheme parallel to the general trend, and the side-valleys in the plateau north of Kena indicate erosion on a scale commensurate with an amount necessary to produce the Nile ravine itself, the evidence at present available points to erosion rather than fracture as the main determining cause of its existence. The remarkable effects produced by erosion alone have been illustrated in the case of the Aswan Dam, where in a very short period of time the scour of the water passing through the sluices had produced great excavations and potholes in front of the main structure. The dam was completed and brought into use during the winter of 1902, and the works necessitated by the erosion were completed in November 1904. In this case even the hardest granite was involved, whereas in the Nile Valley ravine many of the limestone beds are exceptionally soft and friable, and so rapidly eroded.

The limestone scarps in the Nile ravine have been quarried from near Naga Hammadi to Assiut on both sides of the valley, while further north important quarries are present in the eastern scarps, these extending as far as the Mokattam Hills, above Cairo.

In this portion of the valley are deposits formed in freshwater lakes, containing leaves; one of these, the porous siliceous limestone of Isawia, is an important building stone, having been largely used for the Assiut Barrage. Further to the north, the trend of the river may have been determined by the more ready erosion of the softer sands, clays, and limestones which form the upper beds of the Eocene series. From Wasta to Cairo there is a sharp contrast between the long and steep escarpment of the Mokattam Hills, over 200 metres high, on the east, and the low inconspicuous plateau of Upper Eocene strata or still younger gravels, which

would attract little attention were it not the basis on which the Pyramids are founded.

As the edge of the desert near Cairo is approached, there is evidence of greater disturbance in the arrangement of the strata, the Eocene beds of the Mokattam Hills dipping at angles (3° to 5°) far exceeding those observed to the south, and in a southward direction. The lower part of the Mokattam Hills is composed of the White Middle Eocene limestone from which the building materials used in Cairo are obtained. The best variety of building stone in Lower Egypt, known as Batur, is quarried at Atar-el-Nabi, near St George's Station in the low scarp covered by old wind-mills, the strata being an extension of those developed in the cliff behind the Citadel. Many varieties of building stone are also quarried in this series between Cairo and Helwan, the stone being on the whole soft, easily worked, but readily deteriorated.

Strata of similar age rich in *Nummulites gizehensis* form the sloping plateau on which the Pyramids are built, above them both west and east of the Nile being the brown beds of the Upper Eocene, in which sandy limestones and clays with special species of oysters and sea-urchins mark the passage to more shallow-water conditions. The highest beds on both sides of the valley near Cairo are no longer of purely marine origin, as are those at the base, but indicate continental conditions, marked by the presence of the Petrified Forests and a series of sand and gravels.

The present Nile Valley has been formed since their deposition, and was for a time occupied by an arm of the sea, giving rise to raised beaches which have been traced to the neighbourhood of Fashn, and are especially well marked on the edge of the desert fringing the valley between the Pyramids and Sakkara.

In the neighbourhood of the Pyramids is another feature of much geological interest, an old island of folded and fractured Cretaceous rocks, forming the Abu Roash Hills, which are unconformably overlain by the younger members of the Eocene series. This occurrence is at present quite exceptional, the nearest Cretaceous strata being at least 100 kilometres distant, at Gebel Ataka near Suez.

The gradual accumulation of sands and clays brought down by the Nile has resulted in the formation of the Delta, in which the uppermost layers present considerable variations in the surface strata.

From the borings made in the river bed at Esna, in Cairo, or near the large towns of the Delta situated on the branches of the Nile, it has been found that the channel is almost entirely composed of sands, and that the Nile mud is either extremely thin or non-existent. Away from the river, on the other hand, the Nile mud attains a considerable thickness, the sands not being reached till a depth of 10 metres.

In the Nile Valley this succession of Nile mud with sands below is fairly constant, coarse gravels making their appearance at depths of from 30 to 50 metres below the surface. In the borings made by the Cairo Water Company some of the pebbles enclosed in these gravels are over 6 centimetres in diameter, indicating a great change in the character of the stream. These coarse gravels can in some instances be traced to the Red Sea Hills, from whence torrents poured their waters before the connection with Abyssinia was established. In the Delta there is a greater variation in the relation between sands and clays. In the south near Cairo the relations are those of the Nile Valley, but pockets of clay are more frequently present in the lower sands; in the north of the Delta, on the other

hand, pockets of sand are intercalated in the clays, or in some cases alternate with them.

Below this complex association of deltaic muds and sands (more sandy near the river branches, more clayey away from them) are the water-bearing sands similar to those of the Nile Valley, and the question of their precise distribution is one of much interest in connection with drainage. In many parts of the Delta very stiff black clays are intercalated in the sands at varying depths (at Sherbin, for example, at 50 to 60 metres below ground-level); as these contain marine shells such as the common cockle (*Cardium edule*), they represent a temporary gain of the sea, which is also indicated in borings at Alexandria, Kafr Dawar, etc. No boring in the Delta has yet attained the solid rock formations, an effort made at Zagazig on behalf of the Royal Society not reaching these even at a depth of 150 metres.

Stiff black clays of a similar nature are widely distributed in the extreme north of Egypt on the borders of the line of great lakes fringing the Mediterranean, and in their turn will eventually, should events proceed as at present, be covered by river sands or Nile mud.

The Nile Valley sands, in addition to their water-bearing capacity, are largely exploited at Abbassia, near Cairo, for mortar sand, lime brick, and the many other products for which clear white sand is an essential constituent.

4. **Geology of the Fayum and Wadi Rayan.**—There remains a cultivated area to consider, the Fayum, which is among the most interesting occurrences in Egypt, being an inland depression with a large lake, only connected to the Nile Valley by an artificial canal. The depression owes its character to a low northward dip (average 3 degrees) of a hard band of limestone, some 30 metres thick, which forms the summit of the zone with *Nummulites gizehensis* in the desert to the south of the Fayum, and passes underneath the depressions of Gharak and the Fayum itself. The soft limestones of the Ravine series have been removed by denudation, so that the plain is a true dip-slope. In the lowest part of the area is the Birket Karun Lake, which lies in the hollow between the denuded area and the scarp forming the edge of the Western Desert plateau. North-west and north of the lake the ground rises rapidly from the base of the dip-slope of the plain in a series of three escarpments, which represent three important geological series, named by Mr Beadnell the Birket-el-Karun, Kasr-el-Sagha, and Fluvio-Marine series respectively. He describes the intervening plateaux "as being for the most part dip-slope plains formed of hard bands of rock, which resisting denudation, are left protecting the underlying strata, while the softer beds above are cut back at a comparatively rapid rate."

A study of the very rich fossil contents contained in these formations shows them to have been formed under conditions when a sea area was gradually diminishing in depth, and as the land rose a great river was making its effect more and more felt. Throughout the whole thickness of strata displayed in the Fayum and its neighbourhood, these conditions have led to the presence of far greater thicknesses of beds of clay or marls derived from the erosion of land-surfaces than are noticed in series of corresponding age in other parts of Egypt, where purely marine limestones predominate.

The scarps for the same reason present a gradual change, not only in nature of the material composing them, but also in their fossil contents. In the beds below the plains which are pure limestones alternating with clays, only sea-urchins,

Nummulites, and frankly marine animals are present. In the Ravine beds succeeding them the limestones are marly alternating with gypseous clays, and large whales make their appearance among the fossil remains. Above them in the Birket-el-Karun beds sandstones are intercalated between the limestones, and in the Kasr-el-Sagha series above these become not only more marked, but contain remains of large land animals (Barytherium, Mœritherium, the earliest elephant), snakes, turtles, etc.

Finally, in the great Fluvio-Marine formation which closes the series, the sands and sandstones predominate, and contain vertebrate remains which have aroused widespread interest; these include the unique Arsinoitherium, the early elephants Mœritherium and Palœomastodon, giant coneys, crocodiles, all of species at present unknown except from these strata.

The summit of the escarpment is crowned by sands and sandstones with silicified wood and an intercalated sheet of basaltic lava, the edge of the high desert of which it forms the boundary trending W.S.W. and N.N.E.

To the east of the depression a new factor has affected the regular succession of dip-slope and scarp which marks the general structure of the Fayum, the sea having at a relatively modern period (the Middle Pliocene) advanced up the present Nile Valley, which appears to have obtained its present form at that time. Marine shells (especially species of Pecten) are found on the borders of the western desert near the cultivated Nile mud area of the main valley, and closely connected with this series of events is the desert ridge which separates the Nile Valley from the Fayum, and varies in width for 2½ to 10 kilometres, the highest points being situated east of Sersena and Kalamsha respectively. "In both these localities the Eocene rocks are overlain by thick deposits of conglomerate and gravel, attaining altitudes of over 100 metres above the cultivated land below. The slope is usually gradual on the Nile Valley side and more rapid towards the Fayum. Of still later date are the gypseous deposits which cover the plain separating the Nile Valley cultivation from the Fayum depression and gradually rise from the level of the former until they overlie the gravels capping the summit overlooking the Fayum. On the east side this capping of gypsum is often 2 metres thick, and frequently occurs in the pure white crystalline form."

While the marine Pliocene beds attain levels of 60 to 70 metres above present sea-level at Sidmant, the terraces of gravel extend from the northern end to the south-east of the Fayum, attaining an altitude of 170 to 180 metres above sea-level. The most interesting district of the Fayum from the point of view of irrigation is the portion of the dip-slope plain occupied by the Birket Karun Lake, and by the broad cultivated area where Nile alluvium forms the surface covering. The Birket Karun is the shrunken remnant of a far greater lake which once covered a large part of the floor of the Fayum depression, and which, when artificially controlled during the reigns of Amenemhat I. and his successors of the Twelfth Dynasty, formed the famous Lake Mœris. This sheet of water served as a regulator for high and low Nile floods, and during the prehistoric period must have been ten times the size of the present Birket Karun, judging from the extension of the lacustrine clays, which extend from 22 to 23 metres above sea-level, whereas the borders of the present lake are at −20 metres and its centre at −44 metres. This lake forms the lowest portion of the eroded dip-slope plain, and is only fed at the present time by the waters draining from the cultivated lands. The latter owe their presence

to the canal which, leaving the Nile Valley at Lahûn, crosses 5 kilometres of desert and then divides in the wide depression of the Fayum. An interesting feature is the existence of two ravines cut down in many places to the Eocene limestone below the alluvium, which now act as canals or drains. Mr Beadnell has suggested that they were initiated by the escape of water through breaches in the Bahr Yusef during flood time, which have since been deepened to their present dimensions.

There remains a very interesting district to the south-west of the Fayum, the depression of the Wadi Rayan, and especially a bay described by Mr Beadnell (*Topography and Geology of the Fayum Province*, p. 21 *) completely enclosed by cliffs on three sides, and containing three springs at levels of about 20 metres. Two 30-metre bands of hard limestones, separated by 68 metres of softer sandy and clayey beds, represent the geological succession in the cliff, the floor of the depression being sometimes formed by the lower of the limestone bands, though more frequently the sandy and clayey beds occupy this position. Should the question of using the Wadi Rayan as a reservoir come to the front, it will be necessary to determine the nature of the ridge separating the Wadi Rayan from Gharak and the Fayum with greater accuracy than has yet been done, as it is probable that part of this ridge is composed of the clayey and sandy members of the series, which is entirely of Middle Eocene age.

With regard to the question of leaking from a reservoir established in Wadi Rayan, Mr Beadnell has pointed out (*loc. cit.*, p. 24) that the dip of the beds being from south to north, seepage towards the Fayum is not excluded and would be most likely to take place along the junction of the limestone and underlying clayey or sandy beds. Nevertheless, judging from the Eocene beds in the Wadi Rayan, he inclines to the view that no leakage on a large scale would take place, any water escaping from the reservoir owing to the northern dip passing indefinitely to the northward, and not rising to the surface through the overlying limestone at Gharak or in the Fayum.

With regard to the Wadi Rayan holding water, no evidence of serious fissures has been observed, involving its easy escape, and the formation of so vast a water area as the Birket el Karun under somewhat similar geological conditions is encouraging from this point of view. The soundings made from the Nile to Wadi Rayan also indicate a general dominance of limestone for many metres below the valley surface.

With regard to the wider question of earth-movements affecting irrigation constructions, Egypt as a whole now lies outside the greater earthquake regions of the earth's surface, one of these just touching Egypt at Alexandria. Minor shocks frequently take place, but are not of such a nature as to affect the stability of permanent structures. It may indeed be stated without exaggeration that it is much more important to study the underground movement of the river water in times of low and high Nile than it is to consider earth-movements of this nature. Owing to the permeability of the sands underlying the Nile mud, there is a regular rise and fall of the subsoil water in the valley of the Nile, the effects being felt for distances of several kilometres, or, where the valley is narrow, to the edge of the desert itself.

* The materials of this section are mainly founded on the geological descriptions given in this detailed work.

5. **Meteorology of Egypt.** — In this and the next paragraph a summary is given of the meteorology of Egypt from the point of view of the hydraulic engineer. We indicate first the general terrestrial air-circulation with its application to the Nile valley; then discuss in some detail the regimen of the winds in the upper part of the basin, chiefly as affecting the rains; then we come to the distribution of the rainfall; then to the possible change of climate in Lower Egypt within historical times; then to temperature and humidity; and finally to general phenomena not included above.

Extending from south latitude 4° to north latitude 31°·5, the basin of the River Nile lies in a greater variety of climatic regions than that of any other river in the world, and to understand aright their diversity, it may be well to recall the chief factors of climatic difference. The great atmospheric circulation, set up by the variation of the warming effect of the solar rays as we move from equator to poles, is divided into nine zones or belts of five types :—

(1) An equatorial belt, where ascensional movement of the air predominates.

(2) The trade-wind belts, north and south of the first, where the indrawn air moves equatorwards towards the partial vacuum created by the ascension just mentioned, and westwards under the influence of the earth's rotation.

(3) The belts of high pressure in about latitude 30°, due to the heading up of the poleward upper currents, as they feel the constraint of the narrowing meridians in higher latitudes.

(4) The belts of westerly winds, north and south of the last, where there is a general poleward movement of the air, deviated much to the east in consequence of terrestrial rotation, and much interrupted by the huge eddies that give us the storms of the temperate zone.

(5) Circumpolar caps, probably of high pressure.

The climatology of the Nile basin has to do directly with four out of these five types.

The belts are not of invariable position, but move north and south with the sun, though they always lag behind it, and have a much less range in latitude. The simplicity of this ideal arrangement is much modified firstly by the distribution of land and water, and secondly by the presence of hill masses.

So slowly does water warm up and cool down again as compared with the solid crust, especially when the latter is dry and devoid of vegetation, that in summer the sea is cooler than the adjacent land and in winter warmer. Hence in summer a draught is created inwards towards the land, whereas in winter the tendency is for the winds to blow seawards. Again, the updraught caused by terrestrial heating is much intensified if the land

has an upward slope, especially on the sunny side, so that Professor Cleveland Abbe has likened the gentle upward movement over an open plain to the draught of an open fire-place, and the brisker current on a mountain side to the fierce draught of a closed stove with a flue roasted by the flames.

We have already referred to the effect of the earth's rotation in deflecting the winds, but from its importance must touch on it again. In the northern hemisphere this deviation is always towards the right, and in the southern towards the left, and in both cases it is proportional to the velocity of the current and to the sine of the latitude—*i.e.* to the numbers 0, 17, 34, 50 in the latitudes of 0° (Entebbe), 10° (Kodok), 20° (Abu Hamed), and 30° (Cairo), or here practically to the latitude.* Its effect on the east side of a continent north of the equator is to repel an otherwise inblowing southerly current; but on the west side, to deflect it more directly inland. South of the equator the reverse is the case. Hence in South Africa the south-east trade wind blows strongly inland on the Natal side and brings moisture from the ocean, but on the other side the winds are pushed off the land and the country is dry and waterless. On the west coast of north tropical Africa, the inblowing sea breezes are drawn more strongly inland; but on the east, over Somaliland they can move landwards only with difficulty and can never develop any intensity. On the equator, the deflective acceleration is nil, and there is no tendency, on this account, for the south-easterly trade-winds of the southern hemisphere to wheel round into south-westerly winds over the Sudan and Abyssinia (as has frequently been stated).†

A further consequence may be drawn from this deflective acceleration. Air tends to move and winds to blow from regions of high pressure to those of low—that is, across the isobars. No sooner, however, does the air set itself in motion than this force comes into operation and causes the air to blow nearly parallel to the isobars, and with the lower pressure on the left of the current.

We are now in a position to parcel out the Nile basin into its climatic regions. From its extreme south in latitude 4° S. to the equator, the basin lies in the belt of south-easterly trade winds, and Bukoba on the western shore of Lake Victoria may be taken as marking the average limit of their northerly extension, since the percentage of calms is here only slightly greater than that of the south-easterly winds. At Entebbe, and still more

* This law, known as Ferrel's in meteorology, is termed Baer's in hydrography, and has been used to explain the action of the Nile in pressing against its right bank. It is more probable, however, that this effect is due to the prevailing wind, which also blows to the right bank in Egypt. On the White Nile, where the wind blows alternately from N.E. and S.W. (see Table 2), the alternation may have been an important factor in determining the form of the cross-section in a river that had ceased to erode its bed.

† Lyons, *Physiography of the River Nile*, p. 11 and elsewhere.

at Nimulé, the proportion of calms rises very considerably, and we are here in the centre of the equatorial belt. Calms are still prominent at Mongalla, but inasmuch as we have here a seasonal variation from north-easterly wind in the dry season to south-westerly or southerly in the wet, we have left the region of calms and entered that of monsoonal reversal of wind direction—a region pertaining to the trade-winds, and extending as far as Khartoum in an ordinary year, and occasionally to Berber or rarely to Merowe. This region of monsoonal alternation includes, then, the basins of the Bahr-el-Ghazal, the lower Albert Nile, the White Nile, and the whole of the Abyssinian tributaries.

From Shendi to Luxor or Assiut the basin lies under the influence of the steady north-westerly current which may be termed the trade-wind, but certainly not, as is frequently done, the north-east trade-wind. Thence northwards to the Mediterranean Sea we have a region where the north-westerly wind prevails, subject to encroachment at times, especially in winter and spring, by the belt of south-westerly winds. We have thus the following regions :—

i. South-easterly trade-winds up to Bukoba.
ii. Equatorial calms to Lado in the wet season, somewhat south of this in the dry season.
iii. Alternating north-easterly trade-winds and south-westerly monsoon, Mongalla to Shendi.
iv. Steady trade-winds, Shendi to Assiut.
v. Alternating trade-winds and south-westerly cyclonic winds, Assiut to the coast.

We have mentioned the reversal of the wind that takes place over the third region from April or May to September or October, but since the south-westerly wind is the direct bearer of the moisture that gives the Nile flood, and variations of the latter must ultimately be traced to those of the former, we examine the matter in greater detail. In meteorology differences of pressure play a part as important as differences of level in hydraulics. The winter distribution of pressure shows a belt of high pressure in about the latitude of Cairo, stretching westwards to the North Atlantic Ocean, and north-eastwards to join the great winter high pressure area of Siberia, and this system is then at its furthest southerly extension. There is a corresponding belt in the southern hemisphere, which also is then in its furthest southerly position. Close to the equator lies a belt of low pressure. There is thus a slope or pressure gradient for northerly winds over the Nile basin and its surrounding regions. In April and May conditions are beginning to change. The sun is now well north of the equator, and the land in the tropics, baking by day under its nearly vertical rays, gains heat that it cannot radiate away during the shortened night. Every plain is the base of a boiling, ascending mass of hot air, heated and rising during

the day, cooling nearly as much and falling during the night. It is near the mountains, however, that the effects are greatest. Up every valley, but especially those opening on the southern flanks of the hills, rushes a stream of air as a draught up a flue, and where it borders on the ocean it carries with it a plentiful supply of moisture. This rising current is seen at its best round the Abyssinian uplands. On the "roof of the world," the mighty Himalayas, the melting of the snows delays the updraught, but the rare snows of the Simiœn mountains offer no appreciable obstacle to the formation of a little monsoon over the basin of the Blue Nile. From all sides the air drifts up the mountains, but the parched plains of the Sudan send but a dry quota. On the south-east, however, the case is different. The damp surface air of the Indian Ocean is attracted towards the warm hill-mass, and but that it is bending against the deflectional force mentioned above, would reach a higher speed. As it is, it suffices to bring to Abyssinia the *azmera* or light rains of April and May. That they come from the south-east there can be little doubt. Major Gwynn, C.M.G., D.S.O., R.E., quoted by Mr A. Knox,* says, "The effect of the November and February Somali coast rains is felt as far as the foot of the main plateau on the west side of the Hawash."

"In Italian Somaliland, the Somalis divide their year into four seasons, of about three months each, starting from the middle of August (their New Year's Day), namely (1) *Der*, in which the S.W. monsoon still prevails, and which is rainy, until the N.E. winds set in; (2) *Jilal*, a dry season with a constant N.E. wind; (3) *Gu*,† a wet fertile season, in which the N.E. winds prevail, until the S.W. monsoon sets in. The latter wind backs round *by south and then up to east.* It is this wind that brings the rain. It is what is called a 'large' wind, and is known on the coast as *tanganbili*, an expression implying that it serves coasting vessels both from Zanzibar to Benadir and *vice versa*; (4) *Agai* (Hagai), the hot season with lesser rains at intervals, in which the S.W. monsoon is constant."‡

On the Abyssinian railway, it was reported in 1907 that the heaviest wash-outs always came in March or April. The heaviest rainfall of the year at Harrar falls in May; and at Dessie and Quoram, nearly on the eastern watershed, there are distinct secondary maxima in April and May respectively. The prevailing winds at this season are—at Ankober, E.; Adis Ababa, E.; Gore & Wallega, N.E. in April, N.E. and S.E. in May; near Lake Stephanie, E. in April, and variable in May; at Lugh, S.E. in April changing to S.W. in May. The observations at Harrar contradict this view, and the heavy rainfall at Gore and Bure on the S.W. flank of the plateau to some extent points against it also; but on the whole the evidence is for a south-easterly direction of origin for the light rains.

* *The Climate of Africa*, Cambridge, 1911, p. 289.

† *I.e.* February to May.

‡ Knox, *op. cit.*, p. 297.

If the influence of the Himalayas were non-existent, this little monsoon would gain but slightly in strength during the summer, and probably this was the case some 15,000 or so years ago. At that time Europe, the Himalayas, and the high peaks of Central Africa were in the grip of the Glacial period. The Indian monsoon must have been much weaker, and we know that the Abyssinian rainfall was not enough to give us a Blue Nile and Atbara flood, as we have it to-day. Long before their waters could reach Egypt they disappeared, as to-day disappear the floods of the Gash and the Hawash, and other torrents of Northern Africa. But the shrinkage of the glaciers in India brought with it a strengthening of the monsoon, which to-day draws air not only from the region of high pressure over the South Indian Ocean, but also from that over the South Atlantic Ocean. Many points concur in showing that the Indian updraught overpowers that round Abyssinia. The slope of pressure is from St Helena in the South Atlantic towards the Persian Gulf, and the distribution is such as to favour a west or south-west current, but not a south-east one. The wind directions are in general westerly and south-westerly *even on the eastern side of the watershed.* For instance, at Suakin they are W. in both July and August; at Tokar, S.W. from June to September; at Addi Ugri, in Erithrea, W. in June and July, N.W. in September; in Adua, S.W. alternating with N.W.; at Magdala, S.E. and S.W.; at Adis Ababa, S.W. and N.E.; at Lugh, S.W. As already noted, the prevalent wind in Italian Somaliland is south-west. The time of onset of the rains in Abyssinia corresponds to the date of bursting of the Indian monsoon, June 15. There is a weak monsoon rain on the Arabian coast of the Red Sea, but none on the Sudan coast, nor on the south coast of Arabia, and this points to a westerly current.

There is no sign of indraught in the winds blowing along the horn of Africa. All rainfall maps of Africa concur in showing a region of scanty precipitation to the south-east of Abyssinia, between it and the ocean.

On the other hand, the positive evidence for a south-westerly origin of the Abyssinian rain is equally abundant. Not only is there the south-westerly or westerly current (see Table 2), but the western flank of the plateau is the rainiest and has the important rivers. The eastern flank, on the contrary, is among the most arid and barren of the deserts of the world—a fact simply and easily explained by its position in *lee* of the plateau, in the "rain shadow," but inexplicable if it should lie on the windward side.

That the rainfall of Abyssinia from mid-June to mid-September comes from the west or south-west must be conceded, and the question now is, Whence does the current come? No half-way explanation will serve. The rivers run down to the sea, and back to the great oceans we must go for their ultimate sources. We may dismiss at once the claims of the north

wind to be the moisture-carrier. It is a dry wind, becoming hotter and drier on its southward journey; and it may be shown that condensation will begin only at the altitude of Adis Ababa, whereas there is a considerable precipitation below that level. We have the positive evidence that in 1908 an irruption of this north-east wind over the Sudan as far south as Mongalla * was accompanied by a break in the rains. We are left with the alternatives of the South Indian Ocean or the South Atlantic as the final source of the Nile flood. Let us deal with the former first. Easterly and south-easterly winds prevail at this time south of the equator, but interposed between them and the Abyssinian highlands lies the belt of calms. At Entebbe during the three chief months of the Nile flood, there are more than 56 per cent. of calms, and at Nimulé the prevalent wind is an almost calm easterly one, but dead calms predominate. At Entebbe, July, August, and September are the driest three months of the whole year, and much the same is true at neighbouring stations, nor does the rainfall here increase again until after the Blue Nile flood has passed its maximum. In East Africa the cessation of the rains at this season is more marked, and further south the eastern flank of the plateau is practically rainless. There is no evidence of any current of moisture-laden air to be found in this direction, and, besides, it is meteorologically impossible that a current which succeeded in crossing the backbone of the continent without precipitation should begin to give rain heavily as it descended the northern slopes towards the Sudan plains. Every available evidence is against the hypothesis that the rainy wind originates to the south of the basin of the Albert Nile, and ultimately in the Indian Ocean.

By this process of elimination we are left with the third as the only possible place of origin, but this is not the only proof. Observations to the south-west and west of the Sudan are very scanty, but what are available show a south-westerly wind. Of records of prevailing winds on the Congo basin in August that we have been able to find, those for eighteen stations are westerly or south-westerly, three are north-westerly, one is easterly, three south-easterly, and four are southerly; but in the case of several of those that are not from west or south-west it is specially noted that the determination of the true direction is difficult owing to the existence of forest or other local disturbing influences. Where the direction of the lower clouds is noted, they move from south-west. Following the trace further back, to the mouth of the Congo, we find clear evidence of an indraught, all along this coast from Loanda northwards. Such evidence, therefore, as we have of wind direction decides preponderatingly in favour of the continuity of the south-westerly current from the South Atlantic to the Sudan and Abyssinia.

The distribution of pressure favours a drift of the air in this direction

* Keeling, *Cairo Scientific Journal*, 1908, p. 355.

for there is a gradient of 7 millimetres of mercury from St Helena to the centre of Abyssinia, and one of about 16 millimetres from St Helena to the Persian Gulf. This gradient is steep enough to convert the region of closed isobars of April and May—the depression of the little monsoon—into a V-shaped trough whose axis lies north-eastwards, and the formation of this trough is one of the first and most regular signs that the heavy rains are about to commence, as its disappearance is of their withdrawal.

It is impossible to regard a map of the August rainfall in Africa (such as the beautiful one in Mr Knox's *Climate of the Continent of Africa*) without seeing that the rainfall is continuous from the Atlantic coast to Abyssinia, but not from the coast of the Indian Ocean, and the very fluctuations in intensity lend support to the present theory. The heavy rains of the Congo basin continue up to the watershed of the Bahr-el-Ghazal, but on its leeward side moderate considerably, just as we should expect if the Nile lay on the leeward side, but not otherwise. On the other side of the basin of the Albert Nile, however, at about the same altitude on the Abyssinian slopes the isohyet of 200 millimetres is again found.

This theory fits together such isolated relationships as are known between the Nile flood and meteorological facts in other parts of the world. For example, the direct connection between the Nile flood and high pressure in South America in spring, found by Dr Gilbert Walker, F.R.S., Director-General of Indian Observatories, and the closer connection between the flood and pressure at St Helena receive simple and natural explanations, for the higher the pressure in the South Atlantic the greater will be the speed of the current and the rate of precipitation.

Colonel H. E. Rawson has indicated a connection between the weather in South Africa and the Nile flood, and attributes the correlated variation to the position of the southern belt of high pressure. He gives the following table, which we have supplemented by including the years 1906 and 1907.

TABLE 1.—RATIOS OF ANNUAL NILE FLOODS TO MEAN FLOOD (100).*

| Series. | | | | | | | | | | | | Nature of the Floods. | Position of the High-Pressure Belts. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1st Series Floods. | 1869 119 | 1870 124 | 1871 108 | 1872 115 | 1873 88 | 1874 131 | 1875 113 | 1876 113 | 1877 73 | 1878 126 | 1879 120 | In excess. | Far north. |
| 2nd Series Floods. | 1880 103 | 1881 96 | 1882 86 | 1883 108 | 1884 87 | 1885 103 | 1886 94 | 1887 123 | 1888 74 | ... | ... | In defect. | Far south. |
| 3rd Series Floods. | 1889 102 | 1890 117 | 1891 104 | 1892 123 | 1893 101 | 1894 127 | 1895 119 | 1896 110 | 1897 92 | 1898 110 | ... | In excess. | Far north. |
| 4th Series Floods. | 1899 65 | 1900 91 | 1901 89 | 1902 66 | 1903 90 | 1904 76 | 1905 66 | 1906 88 | 1907 60 | ... | ... | In defect. | Far south. |

* Brought up to date and corrected from that given by Col. H. E. Rawson, C.B., R.E., in *Quarterly Journal of the Royal Meteorological Society*, 34, No. 147, p. 166.

It may, however, be that we are here examining not an independent factor, but a different aspect of the phenomenon just referred to.

Again, the retarding effect of excessive snow on the Himalayas in May on the Indian monsoon and Nile flood found by Dr Walker, receives a simple explanation, for it means that the warming-up of the mountains and the consequent updraught are delayed and probably reduced in intensity all through the season. The natural effect is a diminution in the strength of the monsoon current, and as one feeder of this passes across the Abyssinian plateau, the supply of rain here must also be lessened.

The break between the light rains and the heavy rains is then due to the state of equilibrium set up by the conflict between the south-east current and the south-west current and persists till the latter gains the upper hand.

The inverse deviation of the flood and April and May rainfall in Zanzibar, indicated by Lyons and investigated by Walker, is explained because strong south-easterly winds, to which this rainfall is due, are not consonant with a strong development of the south-west current.

The concomitant variations of the gauge readings at Aswan and Bombay rainfall, but not Madras rainfall, found by Sir William Willcocks and Sir John Elliot, are explained because conditions favourable for an abundant Abyssinian rainfall are found in those that favour a strong Bombay monsoon, but not necessarily in those that give a strong Madras one.

The inverse deviation of pressure in North-east Africa and the flood relative numbers, found by Captain Lyons,* is explained by the simultaneous movements of the two high-pressure belts. When the northern belt is further north than usual, and consequently pressure is lower than usual in summer, the belt of the southern hemisphere is also further north and the gradient from the South Atlantic to Abyssinia is increased.

We submit, then, that the theory here adopted co-ordinates and consolidates into an organic whole the known facts as to the connection between the Nile flood and meteorological elements. It does not explain all the variations of the flood, no doubt, but then there are numerous factors not yet studied. There are, for instance, the depth, temperature, and vapour content of the south-westerly current, each of which will by its variations cause variation of the precipitation. There is the possible effect of the trade-wind on the position of the current, for a too strong trade-wind will press the latter too far south and cause increased precipitation on the basin of the Sobat, where it will do little good to the flood, and decreased rainfall on the Atbara basin, which is all-important. Similarly, a too feeble trade-wind will allow part of the current to flow round the plateau rather than be forced over it, and in this case, although there is loss of the

* *Proc. Roy. Soc.*, A, lxxvi., 1905, p. 66.

moisture in the escaping part and diminution of the share from the Blue Nile, there is partial compensation in the increased share from the Atbara. The temperature of the current alone may necessitate a study of that of the Benguela current of cold water that drifts northwards along the coast of South-west Africa and, as has been shown, influences meteorological conditions in the South Atlantic, and this study will certainly take the investigation into the Antarctic. But one day, when the world-wide net of stations, now the subject of international negotiations, cables its daily observations to a central bureau, our knowledge of the great movements of the earth's atmosphere and their variations will be more precise, and it is on these, and not on merely local, parochial causes, that the main variations of the flood will be found to depend. Then the prophecy made ten years ago* that Egypt fifty years hence "will have its weather bureau forecasting seasons and weathers and disseminating information with the aid of wireless telegraphy" will be verified.

Let us take it, then, that the heavy rains in Abyssinia are caused by a south-westerly to westerly current blowing from the South Atlantic across Africa from the middle of June to about the middle of September. The first sign on the plateau that the rains are near their close is the onset of a strong,

TABLE 2.—RESULTANT WIND DIRECTIONS, IN DEGREES FROM N. ROUND BY E., S., AND W.

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alexandria . | 298 | 280 | 331 | 0 | 7 | 340 | 329 | 343 | 353 | 24 | 344 | 294 | |
| Korashia . | 302 | 315 | 329 | 6 | 20 | 0 | 345 | 349 | 8 | 13 | 347 | 330 | |
| Giza . . | 266 | 270 | 317 | 330 | 345 | 342 | 337 | 341 | 340 | 342 | 334 | 270 | |
| Assiut . . | 328 | 327 | 339 | 336 | 336 | 333 | 328 | 329 | 339 | 327 | 315 | 333 | |
| Aswan . . | 360 | 360 | 355 | 355 | 355 | 360 | 355 | 354 | 360 | 355 | 355 | 355 | |
| Wadi Halfa . | 16 | 19 | 21 | 19 | 19 | 14 | 12 | 15 | 12 | 16 | 18 | 19 | |
| Merowe. . | 28 | 24 | 33 | 26 | 24 | 16 | 272 | 276 | 23 | 23 | 34 | 26 | |
| Atbara . . | 0 | 0 | 0 | 7 | 20 | 314 | 302 | 305 | 306 | 37 | 13 | 0 | |
| Khartoum . | 12 | 14 | 22 | 25 | 21 | 224 | 203 | 209 | 222 | 8 | 15 | 14 | |
| Kassala . . | 22 | 20 | 32 | 46 | 169 | 189 | 189 | 182 | 175 | 136 | 41 | 22 | |
| El Obeid . | 10 | 11 | 16 | 7 | 321 | 247 | 225 | 222 | 235 | 336 | 346 | 346 | |
| Roseires . | 349 | 344 | 341 | 290 | 196 | 190 | 189 | 199 | 183 | 196 | 22 | 11 | |
| Kodok . . | 12 | 13 | 13 | 164 | 172 | 180 | 180 | 180 | 165 | 145 | 22 | 6 | |
| Adis Ababa . | 120 | 93 | 110 | 112 | 120 | 65 | 48 | 47 | 77 | 90 | 105 | 90 | |
| Wau . . | 0 | 11 | 0 | 180 | 189 | 239 | 241 | 249 | 231 | 275 | 22 | 353 | |
| Mongalla . | 33 | 19 | 81 | 169 | 162 | 180 | 147 | 162 | 106 | 90 | 76 | 26 | |
| Nimulé . . | 55 | 59 | 59 | 106 | 75 | 75 | 66 | 61 | 57 | 99 | 97 | 79 | |
| Entebbe . | 211 | 180 | 187 | 197 | 180 | 180 | 180 | 198 | 180 | 203 | 191 | 180 | |

* *Egypt Fifty Years Hence*, by W. Willcocks, Cairo, 1902.

dry, easterly current first on the higher peaks, which then rise from the moist current like islands in the sea; then lower and lower, till the rains are driven southwards from the plateau and Sudan plains. In October and November the closed isobar type of pressure distribution reasserts itself as the Indian monsoon depression weakens, but, owing to the lag that takes place before the full effect of the sun's verticality asserts itself, and the fact that in spring the sun's power is increasing as it moves north, while in autumn its power is diminishing, the influence of the autumnal depression is exercised more to the south and does not reach the Abyssinian plateau. As the sun moves further south, the position of greatest ascensional movement moves with it; the Sudan down to latitude 3°·5 N. lies under the north-east trade-wind; the belt of calms embraces the north shore of Lake Victoria, and the south-easterly winds prevail on the southern half.

Having considered the regime of the winds on the Nile basin, we are now able to understand the normal distribution of rainfall as shown in Table 8, which has been specially computed. As usually stated, Africa is said to have a double rainy season near the equator, which merges into a single season north and south of this belt, but a consideration of the table shows that we have to deal with a complex distribution of rainfall, built up of three simpler ones in various degrees of intensity. To begin towards the sources of the river, we note in German East Africa a principal maximum in April, and a secondary one in December to January; but there is also a third feeble but well-marked maximum in July. This last is no accident of sampling, for it is manifest in four out of the five districts, and really existent in the fifth, though masked by the beginning of the autumnal maximum. In British East Africa the vernal * maximum is the principal one, but the summer and autumnal modes are growing in importance. The first two tend to delay into May and August respectively, and the third to advance into November. On the basin of the Albert Nile the vernal maximum is still the highest, and has moved into May; but the summer maximum is of nearly equal importance, and the autumnal one is not far behind. On the basin of the Bahr-el-Ghazal the second is now the chief maximum, and the other two are visible only as swellings on the curve. On the Sobat and Baro † the third maximum has vanished, the second predominates, but the influence of the earlier one on the curve can be seen. In Abyssinia there is no trace of the third; the second is all-powerful; but the first has still a very considerable importance. Kordofan, lying under the lee of the plateau, exhibits only the most meagre trace of the vernal rains, but enjoys a rainfall proportionate to its moderate eleva-

* We use the words "spring," "summer," etc., in an astronomical sense, for brevity. They do not imply any vegetative changes, such as inhabitants of the temperate zone are accustomed to.

† The northern part of the basin, that is, for there are no stations to represent the southern portion.

tion in summer, when it lies on the weather side of the plateau. The basins of the Atbara and Khor Gash, and the plains of the Sudan, lie completely in the rain-shadow of Abyssinia in spring, but exhibit a tolerably good precipitation during the prevalence of the south-westerly current.

From Atbara northwards the basin is practically rainless. The few showers that fall when the moist current is further north than usual may be neglected as far as contribution to the river goes, though they are sometimes heavy enough to give bad wash-outs on the Sudan railway. Rainstorms are almost unknown along the river till we reach Middle Egypt, where we enter a region under a different regimen. The rains of Lower and Middle Egypt fall in winter, as a consequence of the passage of storms eastwards along the Mediterranean Sea at that season. As the annexed plate shows, they are of little importance except near the coast, where their effect on the drains is sometimes very marked. The heavy falls that occur about once in three years in April and May cause damage to the young cotton, and occasionally heavy bursts among the hills cause spates (" seil ") which sweep down into the valley and damage houses and crops. Egypt was not, however, always a rainless land, for geological evidence in the western desert, along Wadi Kena, and in the gravels of the Nile Valley itself, shows that some 15,000 to 20,000 years ago, when Europe was in the grip of the Ice Age, North and Middle Egypt lay well within the belt of westerly winds of the temperate zone, whose moisture, precipitated along the western flank of the Red Sea Hills, fed the Nile of these days—an attenuated river, for the Blue Nile was not then strong enough to force its way north to join this local stream.

This raises the question of stability of the Egyptian climate—within historical times, that is, for no one will maintain, in face of the evidence alluded to above, that the climate has always been as it is now. One school of thought teaches that there has been a decrease in the rainfall all round the East Mediterranean, and on into Asia, and quotes evidence of the former extension of forests where now no trees are, of rivers that once ran in ampler beds than to-day, of formerly prosperous cities that now are only ruins, of dense populations where now there are only scattered nomads, and so on, and attributes the change to slow (and pulsating) decrease in the rainfall. The opposing school would rather lay the blame for these changes on mal-administration. The whole subject has been sifted thoroughly and impartially in a paper by Dr Hermann Leiter.* His general conclusions are that there is no evidence of a change of climate in North Africa within historical times.

There are not wanting people who maintain that the climate of Egypt has changed within the memory of men now living, and compare observations made over a hundred years ago with those of to-day. The com-

* *Die Frage der Klimaänderung während historischer Zeit in Nordafrika*, Wien, 1909.

parison cannot in truth be made with any certainty. The accuracy of the thermometers, their exposure, the thermometric material employed, the hours of observation, the immediate surroundings of the station, all have to be taken into account. A difference in the type of screen employed will easily give a difference of from 1° to 2° C. So will a change in the hours of observation. Temperatures will be lower and humidities higher when measured in a garden than when measured in a sandy compound. Thus while we cannot admit that we have seen any unequivocal proofs of change of climate rather than change of methods, we are prepared to admit a certain fluctuation of climate, and a certain local change such as might be caused by transforming the compound just mentioned into a garden. We have definite proof from the investigations of Mr Balls * that conditions inside a field of cotton are different from and affect to a small extent those outside it. The proofs for fluctuation have been given by Mr Keeling.† The opinion that climate in Egypt has changed is not new. According to Cézanne, certain writers had pretended that plantations made in Egypt had rendered rain more frequent, but Clot Bey had demonstrated the contrary. It is probable that the change is rather a subjective one than an objective one, and is to be attributed to the desire to praise the good old times. As we shall show later, the temperature of Lower Egypt is intimately bound with that of the Mediterranean Sea to the immediate north, and with world-wide changes as yet imperfectly studied, and consequently it is improbable that purely local changes, such as the junction of the Mediterranean Sea and Gulf of Suez, or the extension of irrigation, should produce the alleged change of climate.

We have left the consideration of temperature and humidity to the end, because, although these are the two most important factors of climate in its direct influence on vegetable and animal life, they are so dependent on the wind that without a knowledge of the latter the former are inexplicable.

In Egypt we have to recognise two regions, or perhaps more conveniently three—Upper Egypt, from Wadi Halfa to about Assiut; Middle Egypt, from Assiut to Cairo; and Lower Egypt, from Cairo to the sea. In the first the northerly wind blows the whole year round with the rarest exceptions. The sky is almost cloudless, and rainfall, now as in the time of Herodotus, is limited to a rare storm, probably of electrical origin, and frequently coming from the south. The bare rocks that bound the desert heat rapidly under the unveiled rays of the sun by day and cool down as rapidly by night, and no condensation or absorption of water takes place to mitigate the thermal effects. Hence we have high maximum temperatures and a considerable range. In summer, when the day is longer than

* *British Association Report*, Dundee, 1912.

† *Cairo Scientific Journal*, vol. iii., 1909, p. 7.

the night on the average by nearly two hours, nocturnal radiation is insufficient to permit of the ground losing all the heat acquired during the day, and the average temperature rises steadily till July, when it begins to fall again, as the days shorten. In winter, on the other hand, the case is reversed, and in addition the floor of the valley receives the downflowing cold air from the sides of the plateaux, and the nightly minimum is very low, below freezing-point even on occasion on the higher desert. The air, mixed by daily exchange with that above, contains practically the same amount of water vapour as when it left the shores of the Mediterranean, but has become heated, and therefore relatively drier. The nett effect is that the temperature of the wet-bulb thermometer, to which moist plant tissues and the skin of animals approximate, remains low, and the air feels relatively cool in summer and bitterly cold in winter. But the transpiration of moisture required to balance the evaporation makes so heavy demands on the organism that neither plants nor animals have much energy left for other work. So the southern limit of profitable cotton cultivation lies just south of Assiut, where the mean summer relative humidity is about 35 per cent., and favourable conditions do not start again until, near Berber, we pass into a region with a greater humidity. We shall deal with the effects of the great temperature range on engineering work when we come to discuss the Aswan Dam in CHAPTER XIII.

Middle Egypt is similar in climatic character to that just described, but, being nearer the Mediterranean and further from the equator, suffers less violent extremes of temperature and humidity. It comes also sometimes under the influence of the southerly winds that blow into the winter and spring depressions on the Mediterranean Sea. Here and in Upper Egypt, if anywhere, there will be a future for the direct solar engine, generating electricity on the otherwise waste desert and sending it down to the valley to drive flour-mills, work pumps, and light the towns. The calculated amount of heat received at the earth's surface with average transparency of the atmosphere is given in the following table.

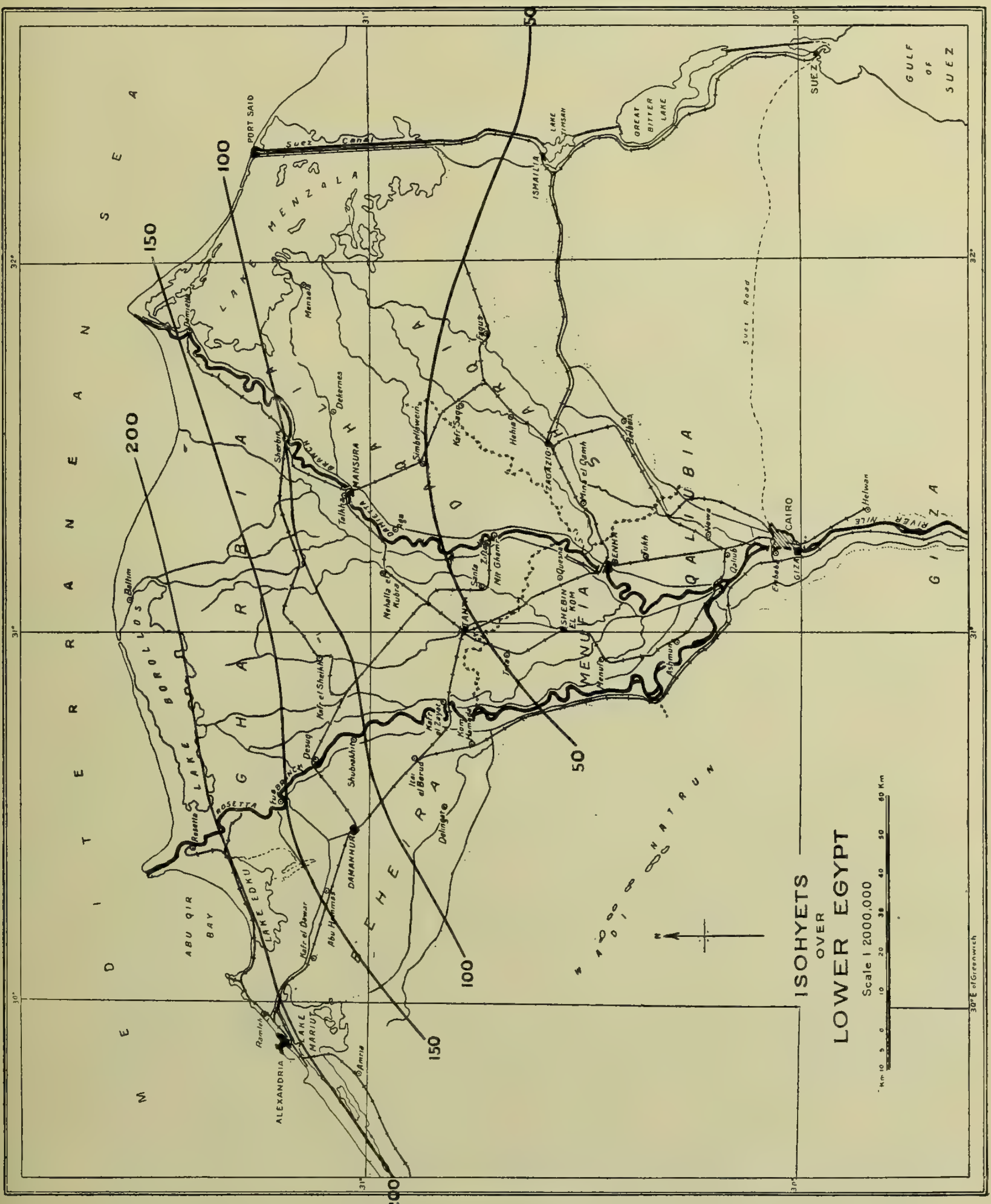
TABLE 3.—MONTHLY TOTALS OF HEAT PER SQUARE CENTIMETRE IN KILOGRAM-CALORIES.*

| Latitude. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° | 14·0 | 14·9 | 15·3 | 14·6 | 13·5 | 12·8 | 13·1 | 14·2 | 15·0 | 15·0 | 14·2 | 13·6 | 170·2 |
| 20 N. | 9·0 | 11·2 | 13·6 | 15·2 | 15·8 | 15·9 | 15·8 | 15·3 | 14·0 | 11·7 | 9·4 | 8·2 | 155·1 |
| 40 N. | 3·3 | 5·7 | 9·4 | 12·9 | 15·3 | 16·2 | 15·6 | 13·5 | 10·2 | 6·6 | 3·8 | 2·7 | 115·2 |

* Modified from that given by Angot, *Annales du bureau central météorologique de France*, tome i., 1883, by taking the amount of heat that arrives at the earth's atmosphere as 2·2 gram-calories per square centimetre per minute.

A surface 100 metres square in latitude 20° N. will receive $10{,}000^2 \times 8{\cdot}2$ kilogram-calories per month in December, provided there are no cloudy days, or $820{,}000{,}000 \times 424$—*i.e.* 348,000,000,000 kilogram-metres, *i.e.* 270,000 kilogram-metres per second, or 2650 kilo-watts. If the average efficiency is as low as 10 per cent., this gives per 10,000 square metres an available power of 265 kilo-watts, in the coldest month, and when the enormous extent available is considered, it is seen that to tap this source of energy becomes merely a question of the expenditure for initial installation and for maintenance. In latitude 30° N., the power will be about half the above in December, but equal to that in latitude 20° N. in summer.

In Lower Egypt surface temperature is controlled chiefly by proximity to the sea in the north. When the north wind blows, as in summer, the mean temperature on the coast is practically that of the sea; but in winter, when south winds are more frequent, these carry to Northern Egypt the cold air of the desert plateaux, and the coast is colder than the sea. At the apex of the Delta, sea temperature is still a predominant factor, but the air is now warmer in summer after its passage over the heated Delta, and colder when the south winds blow in winter, since it is nearer the nocturnal centre of cold air in Middle Egypt. Frost is uncommon, but not unknown, and when it occurs damage to crops and fruit trees results. The air arriving from the Mediterranean is nearly saturated, and when the temperature falls at night below that of the sea-surface, as it frequently does in autumn, winter, and spring, heavy dews or dense fogs result; but though these fogs may produce conditions unfavourable to the cotton plant in some respects, they are not an unmixed evil, for they screen the plants from further radiation and cooling, and the liberation of latent heat also keeps the temperature from falling so low as otherwise it would. There is another factor controlling temperature that can only be mentioned here. Whatever the cause will ultimately turn out to be, it is beyond doubt that temperature in Lower Egypt is bound up with that in South-west England (*i.e.* with the temperature of the North Atlantic Ocean) in such a way that when one rises above normal the other falls below it. This is true in summer to a small extent; but in winter, when both districts lie on the polar side of the tropical high-pressure belt, the relationship is closer than that between brothers in biology. It is less for Egypt and South France and Italy, and becomes a direct relationship for Greece and Egypt; but much work has still to be done before we can parcel out the neighbouring terrestrial surface into two regions, one like, the other unlike, Egypt in their temperature deviations. Nor are we yet in a position to state whether the deviations are strictly contemporaneous, or whether, as seems most probable, one precedes the other and by how much. In certain cases the conditions that favour the cold east winds of spring in England pass eastwards and about a week later give warm khamsins here, and investiga-


ISOHYETS
OVER
LOWER EGYPT
Scale 1 2000,000
MEDITERRANEAN SEA
PORT SAID
Suez Canal
LAKE MENZALA
ISMAILIA
GREAT BITTER LAKE
SUEZ
GULF OF SUEZ
Suez Road
CAIRO
GIZA
Helwan
RIVER NILE
ABU QIR BAY
LAKE EDKU
LAKE MARIUT
ALEXANDRIA
Ramleh
Rosetta
ROSETTA BRANCH
LAKE BOROLLOS
Damietta
DAMIETTA BRANCH
Mansura
MANSURA
ZAGAZIG
BENHA
TANTA
DAMANHUR
Desuq
Kafr el Sheikh
Kafr el Dawar
Abu Hommos
Shubrakhit
Delingat
Benha
Qaliub
Tukh
Mit Ghamr
Simbellawein
Dekernes
Sherbin
Talkha
Faqus
Belbeis
Menuf
Ashmun
Kafr el Zayat
Kom Hamada
Nehalla el Kubra
Zifta
Quesna
Sirs
Dekernes
SHEBIN EL KOM
MENUFIA
QALIUBIA
SHARQIA
DAQAHLIA
GHARBIA
BEHERA
GIZA
WADI NATRUN
Amria
Beltim
200
150
100
50

tion along the line suggested by this clue will be fruitful. It is sometimes stated that the marked rise in humidity that occurs in August is due to the spreading of the flood water; but this is not so, for the increase occurs in Dakhla Oasis, where the effect of the flood must be altogether negligible, and on the north coasts, where the north wind is steadily bringing in the nearly saturated air of the sea. This is a seasonal effect due to the diminution of temperature without any compensating precipitation to lower the humidity.

Of phenomena not yet detailed, the chief is the khamsin wind. There is no essential difference in cause between this and a southerly wind at any other season. Both are due to the passage of low-pressure areas eastwards along the Mediterranean, but whether the south wind is to be warm or cold depends partly on the season, and partly on the position of the ridge of highest pressure. In general, this remains to the west of Egypt, and then the heating of the air is less marked; but when pressure is highest over the Red Sea Desert, we invariably have hot winds. Blowing into the depression, these are ascending currents, and their eddies play a considerable part by raising clouds of dust, each particle of which intercepts the sun's rays and becomes a focus to increase the patch of heat that always precedes a cyclonic storm. At first the wind veers to north-east or east, when the storm centre lies over the central Mediterranean; then it swings round to south-east, south, and south-west as the storm advances eastwards, till when the trough passes and pressure begins to rise again, the wind changes abruptly to north-west, temperature falls, humidity rises, and the dust-laden air is swept away as by magic.

It is not in general till the north wind sets in that we get rain with these storms, for the south wind is too dry to give precipitation, although sometimes there are in the sky all the signs of a heavy rain whose drops evaporate before reaching the ground.

Thunderstorms occur sometimes, but generally in spring and autumn, and they are frequently accompanied by severe hail-storms which do damage to the young cotton in spring. Snow is unknown, but sleet has been recorded at Alexandria.

In contradistinction to the southerly type of weather there is a northerly type in which cold winds of greater force than usual blow down from Russia and give cold or cool weather, according to the season. The intense cold of January 1907, when many cattle and some men perished in Egypt, was due to this cause.

The distribution of rain is shown in Plate II.

Some of the chief climatic elements are summarised in the following table, and full details may be found in the Annual Meteorological Reports and the Statistical Year-book.

TABLE 4.—CLIMATOLOGICAL TABLE FOR EGYPT.

| Station. | January. | | | | | | July. | | | | | | Year. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temperature C. | | | | | Mean Humidity per cent. | Temperature C. | | | | | Mean Humidity per cent. | Temperature C. | | | | | Mean Humidity per cent. |
| | Mean. | Maximum. | Minimum. | Absolute Maximum. | Absolute Minimum. | | Mean. | Maximum. | Minimum. | Absolute Maximum. | Absolute Minimum. | | Mean. | Maximum. | Minimum. | Absolute Maximum. | Absolute Minimum. | |
| Alexandria . . | 13·5 | 18·0 | 10·3 | 26·1 | 4·0 | 64 | 25·5 | 30·4 | 22·7 | 37·0 | 17·5 | 73 | 20·0 | 24·8 | 17·0 | 44·9 | 3·0 | 68 |
| Port Said . . | 13·6 | 19·0 | 8·9 | 28·9 | 1·4 | 76 | 26·0 | 32·2 | 21·7 | 41·4 | 13·0 | 76 | 20·4 | 26·2 | 16·1 | 43·0 | 0·0 | 74 |
| Korashia . . | 10·0 | 17·0 | 8·6 | 21·8 | 0·0 | 86 | 26·0 | 33·0 | 22·5 | 41·7 | 16·2 | 67 | 18·6 | 25·7 | 16·2 | 43·5 | 0·0 | 77 |
| Suez . . . | ... | 19·1 | 7·9 | 25·0 | 1·5 | ... | ... | 35·1 | 21·9 | 41·5 | 21·0 | ... | ... | 28·4 | 15·5 | 41·5 | 1·5 | ... |
| Cairo (Abbassia) . | 12·3 | 18·2 | 6·8 | 28·1 | −0·7 | 71 | 28·5 | 36·0 | 20·9 | 44·3 | 15·0 | 54 | 21·2 | 27·9 | 14·3 | 44·6 | −0·7 | 62 |
| Kasr el Gebali . | 10·6 | 18·9 | 5·3 | 29·5 | −1·0 | 74 | 27·9 | 36·9 | 19·4 | 42·7 | 18·0 | 58 | 20·2 | 28·7 | 12·9 | 44·5 | −1·0 | 65 |
| Assiut . . . | 11·2 | 20·9 | 4·7 | 30·5 | 0·0 | 69 | 29·3 | 37·6 | 22·2 | 44·5 | 15·5 | 40 | 21·4 | 30·7 | 14·4 | 49·0 | 0·0 | 53 |
| Aswan . . . | 14·5 | 23·5 | 9·1 | 37·2 | 3·0 | 52 | 32·6 | 41·8 | 25·3 | 47·2 | 20·6 | 30 | 24·9 | 34·5 | 18·4 | 50·0 | 2·5 | 39 |

6. **Meteorology of the Upper Basin of the Nile.**—The upper basin of the Nile may be divided into the following climatic regions, some of which are capable of further subdivision.

(1) *The North Sudan, from Wadi Halfa to Berber.*—This is continuous with, and indistinguishable from, the region of Upper Egypt. The northerly winds persist throughout the year with but rare exceptions. The air is extremely dry, the range of temperature is great, and its mean temperatures place it amongst the hottest parts of the globe. In winter the minimum temperature may be so low that the ripening of cotton is prevented, and when, as in 1910, there is a spell of low nocturnal temperature in November, cotton cultivation may be a failure as far south as Atbara.

(2) *The Central Sudan, down to about latitude* 9° *N.*—In winter the wind is prevailingly from north or north-east, and there is a considerable range of temperature and great dryness. In April, May, and June, before the rains begin, winds are still northerly on the whole, the heat is extremely oppressive, and the air very dry; but the mean temperature is less than in the North Sudan where the moderating effect of vegetation is absent. During the dry season dust-storms, called haboobs, are frequent. Their meteorology deserves a study which it has not yet received. From July to October wind direction lies between west and south, the air is much damper and cooler, the sky is cloudy, and the rainy season prevails. Many parts of this region resemble in climate Arizona and Texas, where the system of "dry-farming" is profitably worked. The rainfall is too variable to give certainty to agriculture, and one of the problems of the engineer is so to supplement the scanty rainfall as to bring as much as possible of the vast fertile districts bordering the Blue Nile and White Nile under steady cultivation.

(3) *The Abyssinian Plateau.*—This is high enough to permit of three main subdivisions into *Kwolla*, the low-lying lands round the base of the plateau and in the valley floors; *Woina Dega*, or intermediate zone, from 1500 to 2300 metres; and *Dega*, or uplands over 2300 metres. In the Kwolla the air is hot and moist in the rains, but dry at other times, and malarial and other fevers are common. Cotton, sugar, bamboo, rubber, tobacco, and coffee do well in the Kwolla. Cereals, fruits, and vegetables all thrive in the Woina Dega; and the Gallas want but little training and help from improved implements to take rank amongst the best farmers in the world. The Dega is too cold for crops, but affords excellent pasturage.

The middle zone is admirably suited for European residence, being cool and bracing.

The regimen of the rains has already been mentioned.

(4) *The South Sudan.*—In the Bahr-el-Ghazal and on the lower Albert Nile the climate is hot and damp through the year. Winds are light—

TABLE 5.—MEAN TEMPERATURE (Centigrade).

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entebbe (10) | 22·1 | 22·1 | 22·2 | 21·1 | 21·2 | 21·0 | 20·7 | 20·5 | 21·3 | 21·8 | 21·8 | 21·8 | 21·5 |
| Nimulé (6) | 26·7 | 27·1 | 27·3 | 27·3 | 26·6 | 26·4 | 25·2 | 24·6 | 25·3 | 26·4 | 26·4 | 25·5 | 26·2 |
| Mongalla (9) | 26·9 | 27·3 | 28·2 | 27·1 | 25·8 | 25·2 | 24·2 | 24·1 | 25·5 | 25·8 | 26·3 | 26·2 | 26·0 |
| Wau (9) | 26·0 | 27·0 | 29·0 | 29·4 | 27·9 | 26·4 | 25·4 | 25·1 | 25·8 | 26·3 | 26·4 | 25·3 | 26·7 |
| Gambela (2½) | 26·2 | 28·5 | 29·8 | 29·0 | 27·6 | 26·8 | 26·1 | 25·7 | 25·2 | 26·1 | 26·0 | 25·3 | 26·8 |
| Adis Ababa (9) | 15·0 | 16·2 | 17·3 | 17·3 | 17·7 | 16·1 | 14·8 | 14·5 | 15·1 | 15·5 | 14·5 | 14·1 | 15·7 |
| Kodok (6) | 25·0 | 26·6 | 29·4 | 29·4 | 27·6 | 25·2 | 23·8 | 24·1 | 25·2 | 25·6 | 25·8 | 24·6 | 26·0 |
| Roseires (7) | 23·7 | 25·8 | 27·8 | 30·0 | 29·4 | 26·3 | 24·4 | 23·8 | 24·0 | 25·6 | 25·5 | 23·9 | 25·8 |
| Wad Medani (10) | 22·1 | 23·5 | 27·0 | 30·6 | 31·9 | 30·9 | 28·0 | 27·4 | 28·0 | 29·2 | 27·3 | 23·3 | 27·4 |
| Khartoum (12) | 21·2 | 23·3 | 26·0 | 30·1 | 32·7 | 33·2 | 31·4 | 30·6 | 31·2 | 30·9 | 26·7 | 22·3 | 28·3 |
| El Obeid (10) | 19·4 | 21·3 | 24·1 | 28·3 | 29·7 | 29·2 | 27·0 | 26·2 | 26·7 | 27·4 | 24·3 | 20·3 | 25·3 |
| Kassala (10) | 23·3 | 25·0 | 27·5 | 30·8 | 32·5 | 31·1 | 28·1 | 27·3 | 28·2 | 29·7 | 28·2 | 24·5 | 28·0 |
| Atbara (10) | 20·0 | 21·1 | 24·9 | 29·1 | 32·8 | 33·7 | 32·2 | 32·0 | 31·9 | 30·3 | 25·8 | 21·3 | 27·9 |
| Merowe (7) | 19·7 | 21·1 | 24·4 | 28·9 | 32·6 | 34·0 | 33·3 | 33·1 | 33·0 | 30·6 | 25·5 | 20·5 | 28·0 |
| Wadi Halfa (21) | 14·7 | 16·5 | 20·9 | 26·1 | 30·2 | 31·9 | 31·8 | 31·3 | 29·8 | 27·4 | 21·0 | 16·2 | 24·8 |

The number of years used for the averages is given in brackets after the name of the station.

TABLE 6.—MEAN TEMPERATURE OF THE WET BULB THERMOMETER (Centigrade).

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entebbe | 19·6 | 19·3 | 19·6 | 19·4 | 19·2 | 18·7 | 18·7 | 18·3 | 18·9 | 19·3 | 19·5 | 19·6 | 19·2 |
| Nimulé | 22·2 | 22·6 | 24·6 | 22·1 | 22·7 | 22·9 | 22·2 | 23·1 | 22·9 | 23·2 | 22·8 | 21·2 | 22·7 |
| Mongalla | 20·8 | 21·4 | 22·0 | 23·3 | 23·0 | 23·0 | 22·4 | 22·3 | 23·0 | 23·0 | 22·8 | 21·4 | 22·4 |
| Wau | 18·6 | 19·6 | 21·4 | 23·6 | 24·5 | 23·8 | 23·6 | 23·4 | 23·8 | 23·8 | 22·2 | 18·8 | 22·2 |
| Gambela | 20·1 | 20·9 | 21·9 | 23·6 | 23·8 | 23·7 | 23·2 | 23·3 | 22·0 | 22·1 | 21·9 | 20·5 | 22·2 |
| Adis Ababa | 9·9 | 11·3 | 13·0 | 13·3 | 12·8 | 13·0 | 12·7 | 12·6 | 12·4 | 10·1 | 9·0 | 9·3 | 11·6 |
| Kodok | 15·2 | 17·2 | 19·2 | 21·7 | 22·2 | 22·1 | 21·9 | 22·4 | 23·1 | 22·8 | 20·2 | 16·7 | 20·4 |
| Roseires | 16·4 | 17·1 | 17·8 | 19·7 | 21·8 | 22·0 | 21·7 | 21·6 | 21·7 | 22·2 | 19·6 | 17·0 | 19·9 |
| Wad Medani | 14·4 | 13·8 | 14·6 | 16·4 | 19·4 | 21·4 | 22·0 | 22·2 | 22·2 | 20·8 | 17·1 | 14·8 | 18·2 |
| Khartoum | 12·0 | 12·8 | 13·5 | 16·0 | 18·8 | 21·2 | 23·2 | 23·4 | 22·7 | 20·0 | 15·6 | 12·9 | 17·7 |
| El Obeid | 11·0 | 11·8 | 12·8 | 16·5 | 19·0 | 21·0 | 22·2 | 22·9 | 22·3 | 20·2 | 15·0 | 12·2 | 17·2 |
| Kassala | 16·5 | 17·4 | 18·2 | 18·8 | 21·2 | 21·6 | 21·9 | 22·6 | 22·5 | 21·2 | 20·0 | 17·6 | 20·0 |
| Atbara | 13·3 | 13·6 | 14·8 | 16·6 | 19·4 | 20·9 | 22·6 | 23·0 | 22·2 | 20·2 | 17·4 | 14·4 | 18·2 |
| Merowe | 11·4 | 11·5 | 12·2 | 14·7 | 16·6 | 17·3 | 19·8 | 20·2 | 19·0 | 17·8 | 14·8 | 12·0 | 15·6 |
| Wadi Halfa | 9·5 | 9·9 | 12·5 | 15·2 | 17·2 | 18·6 | 19·6 | 20·2 | 19·8 | 18·5 | 14·1 | 11·1 | 15·5 |

The temperature of the wet bulb thermometer approximates to that experienced by plants and animals.

TABLE 7.—RELATIVE HUMIDITY.

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Entebbe (10) | 78 | 76 | 77 | 85 | 82 | 79 | 82 | 80 | 78 | 78 | 80 | 80 | 80 |
| Nimulé (6) | 66 | 66 | 79 | 62 | 70 | 73 | 76 | 87 | 81 | 75 | 72 | 67 | 73 |
| Mongalla (9) | 56 | 57 | 56 | 71 | 78 | 82 | 85 | 85 | 80 | 78 | 73 | 64 | 72 |
| Wau (7) | 46 | 46 | 48 | 59 | 74 | 79 | 85 | 86 | 84 | 80 | 68 | 51 | 67 |
| Gambela (2½) | 55 | 48 | 47 | 62 | 71 | 76 | 77 | 81 | 74 | 69 | 68 | 63 | 66 |
| Adis Ababa (5) | 48 | 52 | 58 | 61 | 54 | 67 | 77 | 79 | 71 | 46 | 43 | 49 | 59 |
| Kodok (5) | 30 | 35 | 34 | 48 | 61 | 75 | 84 | 86 | 83 | 78 | 58 | 41 | 59 |
| Roseires (7) | 43 | 38 | 33 | 34 | 49 | 67 | 78 | 82 | 81 | 73 | 55 | 47 | 57 |
| Wad Medani (10) | 38 | 27 | 18 | 16 | 26 | 40 | 57 | 62 | 58 | 44 | 31 | 34 | 38 |
| Khartoum (12) | 26 | 22 | 16 | 16 | 21 | 30 | 47 | 52 | 45 | 32 | 25 | 27 | 30 |
| El Obeid (10) | 28 | 24 | 19 | 24 | 32 | 45 | 64 | 74 | 67 | 48 | 31 | 32 | 41 |
| Kassala (10) | 46 | 43 | 36 | 27 | 32 | 40 | 56 | 65 | 59 | 43 | 43 | 48 | 45 |
| Atbara (10) | 42 | 38 | 28 | 21 | 24 | 27 | 40 | 43 | 40 | 36 | 40 | 42 | 35 |
| Merowe (7) | 29 | 23 | 14 | 13 | 12 | 12 | 24 | 26 | 21 | 22 | 25 | 30 | 21 |
| Wadi Halfa (21) | 47 | 37 | 31 | 25 | 21 | 22 | 27 | 32 | 35 | 38 | 42 | 50 | 34 |

TABLE 8.—NORMAL RAINFALL (in millimetres) BY DISTRICTS (to the end of 1911).

| | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| German East Africa— | | | | | | | | | | | | | |
| Coast | 100 | 73 | 129 | 245 | 156 | 32 | 41 | 30 | 28 | 41 | 95 | 103 | 1073 |
| Intermediate | 119 | 92 | 151 | 258 | 184 | 29 | 48 | 28 | 27 | 55 | 95 | 117 | 1203 |
| Inland | 144 | 124 | 158 | 181 | 68 | 11 | 19 | 13 | 14 | 25 | 79 | 120 | 956 |
| North East | 73 | 69 | 134 | 336 | 260 | 53 | 55 | 34 | 38 | 68 | 127 | 93 | 1340 |
| Lake Plateau | 93 | 95 | 173 | 295 | 170 | 34 | 21 | 43 | 61 | 87 | 161 | 136 | 1369 |
| British East Africa— | | | | | | | | | | | | | |
| Coast and Zanzibar | 35 | 18 | 69 | 199 | 340 | 92 | 92 | 47 | 43 | 68 | 124 | 49 | 1176 |
| Inland | 31 | 33 | 74 | 177 | 111 | 52 | 46 | 59 | 35 | 61 | 142 | 75 | 896 |
| Lake Plateau | 58 | 82 | 136 | 227 | 180 | 139 | 113 | 143 | 113 | 104 | 113 | 111 | 1519 |
| Uganda | 51 | 51 | 129 | 202 | 169 | 72 | 68 | 136 | 114 | 128 | 130 | 93 | 1343 |
| Albert Nile | 4 | 16 | 42 | 86 | 140 | 99 | 116 | 138 | 116 | 106 | 52 | 10 | 925 |
| Bahr-el-Ghazal | 1 | 7 | 16 | 59 | 120 | 142 | 178 | 202 | 153 | 99 | 12 | 0 | 989 |
| Sobat (and Baro) | 8 | 11 | 38 | 89 | 142 | 169 | 174 | 217 | 165 | 96 | 44 | 11 | 1164 |
| Kordofan | 0 | 0 | 3 | 13 | 32 | 51 | 101 | 114 | 81 | 40 | 1 | 0 | 436 |
| Abyssinia | 9 | 17 | 74 | 85 | 95 | 97 | 227 | 258 | 136 | 21 | 20 | 11 | 1050 |
| Atbara and Gash | 0 | 1 | 5 | 9 | 27 | 64 | 137 | 141 | 81 | 23 | 5 | 2 | 495 |
| Blue Nile (Sudan) | 0 | 0 | 2 | 10 | 28 | 57 | 130 | 138 | 100 | 26 | 3 | 0 | 494 |
| Red Sea Coast | 18 | 9 | 12 | 5 | 2 | 1 | 4 | 5 | 3 | 13 | 38 | 21 | 131 |

from north chiefly in the dry season, from south during the rains. The range of temperature is not great either from day to night or during the year, and this monotony of climate, combined with steady dampness, helps to render these districts unhealthy and uninviting.

(5) *Uganda and the Upper Albert Nile.*—The climate is mild—slightly cooler than the South Sudan, owing to its greater altitude, but damp and unhealthy. All along the river and the shores of the lakes malaria is frequent, but in the higher country between Lake Victoria and Lake Albert the air is cool and invigorating. The chief rains fall in spring, but the summer and autumn rainy seasons are not unimportant. To the south of Lake Albert the autumnal is the principal rainy season.

7. **The Soil of Egypt.**—In the second edition the subject was thus treated :—

" The soil of Upper Egypt, and Lower Egypt down to a contour of 7 metres above the Mediterranean, is practically free from salt in excess, except where very high lands are being perpetually irrigated by lift, and never washed by a flood. Below a contour of 7 metres, however, bad drainage is always accompanied by salt efflorescence. Below a 3-metre contour, salt is everywhere in excess, and the land needs very careful drainage and frequent washings. Below a 1·50-metre contour, the land has practically still to be reclaimed. When it is considered that the bottom deposits of Nile alluvium have always been in sea water, and that up to 1·50 metres above sea-level they have frequently been washed by the sea, it is not to be wondered at that capillary attraction brings salt easily to the surface in the northern part of Lower Egypt. In Lower Egypt, above a 6-metre contour, wells are frequently used for irrigation; the springs are from 3 to 6 metres below the surface. The higher the spring level the sweeter the water; wells in black clay soil give much less, but much sweeter water than those in sand. Below a 6-metre contour, wells are very seldom used, possibly because the water is salt. In the Upper Egypt basins, wells are dug everywhere for summer irrigation; the water is from 3 to 7 metres below the surface, and sweet.

"The rise and fall of spring levels depends on the soil, which varies considerably. Where the ordinary compact clay soil of Egypt is met with, the rise of the Nile has not much effect at the surface of the country. The Nile may be 3 metres above the level of the country, and the fields will be as dry as in the height of summer. Where, however, the soil is sandy, a few days after the Nile has risen about a metre above the level of the country, every field becomes a stagnant pool of black water, which reaches up to half a kilometre from the river, and in some places even a kilometre. Immediately the Nile falls, however, the spring level falls with it. The water in the wells rises and falls with the river, much in some places, little in others. At a well near Cairo, in apparently sandy soil, Sir J. Fowler found the water rise 3·7 metres above its minimum, while the Nile rose 6·1 metres. The wells in the Delta depend for their springs as much on the main canals as on the Nile itself. The spring level in the southern half of the Delta proper has been permanently raised by the extra height to which the water has been held up in summer at the Barrages since 1884. Fellahin have frequently informed me, that owing to this rise they have been enabled to put in extra wells, both on account of the extra

water, and of the easiness of lifting it 2 metres or so less than before. (This rise of spring level constitutes a very great danger to Lower Egypt.) In low hollows and tanks in the clay soil there is little water during the floods, as evaporation is more active than infiltration in such soil. During winter, however, the infiltrations continue, the evaporation decreases, and the tanks soon fill. In clay soil, therefore, infiltration may be taken as less than the evaporation in summer."

Soil is that part of the earth's crust which is subject to tillage. The subsoil is the part under it. Both consist of a mixture of minerals, organic matter, water, and air. Soil is classed as:—

(1) Stiff clay if the particles are under ·005 millimetre.
(2) Silt ,, ,, between ·005 and ·05 millimetre.
(3) Sand ,, ,, ,, ·05 and 1 millimetre.

Equal parts of clay and sand make loam. The extremes are unfitted for cultivation.

Dr W. F. Hume has thus written in *The Study of Soils in Egypt*:—

"It is generally accepted that four important elements enter into the problem under consideration:—

(1) The climatic factor.
(2) The geological factor.
(3) The time factor.
(4) The influence of vegetation and animal life."

The climatic factor has already been considered in paragraph 5. The time factor is of little moment in Egypt, while the influence of vegetation and animal life will be considered in CHAPTER XIV. There remains the geological factor.

"The geological factor in Egypt possesses elements which at first sight tend to simplicity. In most temperate climes, soil variations depend on the weathering changes undergone by subjacent geological formations, but in Egypt, almost the whole of the agricultural land has been deposited from the Nile.

Sir W. Willcocks (*Egyptian Irrigation*, 2nd edition, 1899, p. 173) recognised four classes of soil, noting:—

(1) The well-known dense black clay soil of a depth of over 6 or 7 metres, which is very rich and especially suitable for cotton. It is injured very slowly by infiltration and saturation, but once injured its reclamation is slow and stubborn. Such soil has not been anywhere injuriously affected by heavy irrigation, except where the canals have been run at a high level throughout twelve months of the year.

(2) The next class of soil is a dense black clay of from 1 to 3 metres in depth, overlying sand. Previous to the heavy irrigation of recent years, the land was everywhere studded with wells which were worked in winter and summer. Wherever canals running during those seasons at a level higher than that of the country have been introduced, the deterioration of the soil has been very marked. Where, however, canals running at a level of about 2 metres below the surface in winter and summer have been introduced, the spring level has risen to that of the water

in the canals, the wells have become more powerful, and the happiest results have been obtained.

He pointed out that the basin tracts are principally composed of these first two classes.

(3) The third class of soil is a sandy clay, especially suitable for maize and root crops, and where high-lying very rich. According to him, the introduction into such lands of canals running at a high level in winter and summer has meant the conversion of the country into marshy soil with great accumulation of salts at the surface, and it is suggested by him that during those seasons the canals should be maintained below ground level. This class is specially noticeable near the canals.

(4) The fourth class is almost pure sandy or gravelly soil, occurring at various localities in the Delta itself, and forming the desert edges in the Nile valley.

This classification is, however, too generalised for our present purpose, and the warning given by M. Mosséri (*Le Drainage en Egypt*, p. 104), taken in conjunction with Mr Hughes' work, needs to be borne in mind. M. Mosséri writes: 'This classification is a little too simple, for there is clay and clay, side by side, with differing properties.'

In the *Year-Book of the Khedivial Agricultural Society* have appeared a series of studies by Mr F. Hughes. He shows that the large differences in the physical nature of Nile soils are due to two causes, the first and most important being the separation of the particles of the silt by variations in the flow of the river or water from which the deposit was formed, the second the admixture of wind-blown desert sand with the true alluvium, thus producing a 'diluted' alluvial soil (*Year-Book Khedivial Agricultural Society*, 1906, 'Notes on Egyptian and Soudan Soils,' p. 133). Six soils were taken as typical from Kena province, and divided into two groups of three, according to their mechanical analysis. Group A, representative of light soils, gave 80 per cent. of coarse and fine sand to 18 per cent. fine silt and clay. Group B, representative of the heavier soils, gave 30 per cent. coarse and fine sand, and 64 per cent. fine silt and clay, yet analyses for potash and phosphoric acid showed little difference between them.

When, however, the changes were due to mechanical admixture of desert sand the results were very different, there being in general a rapid drop in the percentage of both potash and phosphoric acid as the coarse sand content increased. The table is as follows:—

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| Coarse sand . . . | 29·6 | 54·8 | 74·5 | 84·5 |
| Total potash . . . | 0·58 | 0·29 | 0·34 | 0·09 |
| Total phosphoric acid. . | 0·40 | 0·30 | 0·19 | 0·10 |

Messrs Pellet and Roche consider that the physical constitution of Egyptian soil varies greatly according to locality, and even in the same field.

In the direction of the analysis of soils on sound geological lines, a commencement was made by Mr A. Lucas, who in 1902 published *A Preliminary Investigation of the Soil and Water of the Fayum Province.*

The facts that came out strongly from the investigation were:—

(*a*) The desert sands and gravel beds, with the limestones and clays underlying them, are particularly rich in chlorides and sulphates.

(*b*) The subsoil of the cultivated land in the three cases examined, showed

a much larger proportion of injurious constituents than the respective surface sample.

(*c*) On American standards, even the land bearing good crops is only comparatively good.

(*d*) The low-lying lands are being sacrificed to those at a higher level, the areas occupied by efflorescences being generally lower than the surrounding fields.

The preliminary conclusions so obtained were strengthened by further study embodied in *A Report on the Soil and Water of the Wadi Tumilat Lands under Reclamation*, by the same writer. The construction of the Ismailia Canal in 1863 led to the ruin of the Wadi Tumilat, the salts already present in the soil being brought to or near the surface by the action of the infiltration water with disastrous results.

The drainage from the desert areas is equally liable to introduce injurious materials.

In his *Chemistry of the River Nile*, 1908, Mr Lucas carried the study a considerable step further, physical analyses being made of a number of samples from well borings preserved in the Geological Museum.

In the *Year-Book of the Khedivial Agricultural Society* for 1905 (see tables on pp. 238 and 239) Dr W. C. Mackenzie discussed the composition of the suspended matter in the Nile-flood waters and typical Egyptian soils from analyses made by Mr Burns, of the Giza School of Agriculture. These bring out strongly the intimate relation between the Egyptian soil and Nile mud. With regard to the substances in solution, the general conclusion is that sodium chloride varies between wide limits during the year, its average content being 2·30 parts per 100,000. Each acre of land under perennial irrigation receives on an average about 4000 cubic metres of water per annum, this being equivalent to an addition of 96 kilos of common salt per annum. The obvious suggestion is that efficient drainage is a prime necessity. Sulphates also increase during the low Nile period, but the most striking feature in the analyses is the ratio of soda to potash. During low Nile, soda is to potash as 3 to 1; during the flood this figure is reversed, the ratio being 1 to 3.

An interesting series of researches has been undertaken by Messrs M. H. Pellet and R. Roche ('Composition du sol égyptien,' *Bull. de l'Inst. Egypt.*, déc. 1907), on the Naga Hammadi soils. The results show a very homogeneous character as regards their composition, especially noticeable in contrast with the Delta being the percentage of calcium carbonate (5 to 7 per cent.). The carbonate of lime appears to be of still greater importance in the Sudan regions, where deposits of 'kunkar' of considerable extent are found in the soils bordering the Blue Nile and in those of the Gezira.

The Naga Hammadi deposits also contain on an average 20 to 65 per cent. of sand, 20 to 60 per cent. of clay, and 0·8 to 1·3 per cent. of humus. Magnesia is in large quantity (from 1 to 3 per cent.), nor is manganese oxide unimportant (·05 to ·2 per cent.). Fertilising elements (phosphoric acid, potash, nitrogen) vary from 3·37 to 6·58 per cent.

The general conclusion of this work compared with a series of analyses from other sources is as follows: (1) Egyptian soil is very uniform in its general composition; (2) it is very rich in potash, somewhat less rich in phosphoric acid;

and (3) poor in nitrogenous compounds. The high percentage of magnesia and the presence of manganese are general from the Delta to Aswân.

A series of researches has also been undertaken in the same direction by M. Raoul Roche, the results appearing in the *Bull. Inst. Egypt.*, vol. ii., 5th series, 1908, under the titles 'Importance de l'étude physique des sols' (pp. 47–54) and 'Essai d'étude des propriétés physiques des terres de la Haute-Egypte' (pp. 55–67). In the first of these papers, he discusses the importance of water-circulation to a country like Egypt. This leads directly to a study of the soils themselves, which in Egypt fall into two large categories: (*a*) sandy soils, known in Egypt as '*safra*' lands (Ard Safra); (*b*) clayey soils, known as black or '*soda*' lands (Ard Soda).

From the point of view of chemical analysis there is no very marked difference between these two types of soil. Physically, however, the contrast is very great, owing to the variable relations between the clays and sands. M. Roche has classified these, according to the percentage of clay present, as follows: (1) very light *safra*, 20 per cent.; (2) *safra*, 20 to 30 per cent; (3) intermediate medium, 30 to 40 per cent.; (4) strong *soda* (*essouedt fortes*), 40 to 60 per cent.; (5) very strong *soda*, 50 to 60 per cent. Owing to the greater water-holding power of the heavy soils, plant-life, and especially sugar-cane, is less liable to suffer on 'safra' lands than on the heavy soils, Sachs' experiments having shown that in a clayey soil a tobacco plant will fade when the humidity falls below 8 per cent., whereas in a soil of quartzose sand the humidity may be as low as 1·5 per cent. before the same effect takes place.

The interrelation of plant-life to the nature of the soil is also shown by M. Mosséri in a paper entitled *La Maladie Vermiculaire*, *causée par l'Heterocdtora radicicola*, Paris, 1903. In a preliminary note in this paper, attention is called to the fact that *Orobanche tinctoria*, which he had in the previous year shown to be a parasite on beetroot, was really a plant loving siliceous soils, the clayey compact soils, which become cracked during the dry season, being almost free of it. It is possible to see areas with the parasites and others without them side by side, analyses at once showing the difference in the proportion of silica present.

In the comparison of these two types of soils, attention must also be called to a problem presenting itself in Egypt which only has its parallel in the countries situated in the interior of continents. It is the cracking of the heavy soils, which presents serious difficulties in Upper Egypt and the Sudan. The question is, however, one of the special cases dependent on the evaporating power, temperature, nitrification, etc. A summary is given by M. Roche of the characteristics of the two soil types, with certain conclusions as to their relative agricultural value. For sugar-cane, as an example, the heavy soils only give a return of 60 per cent. compared with the results obtained on *safra* lands.

In the discussion on this paper, M. Mosséri pointed out the importance of the fact that when the amount of humidity in a given soil falls below a certain degree, capillarity ceases almost entirely.

An excellent summary of the Egyptian soil question is given in the *Text-Book of Egyptian Agriculture*, edited by Foaden and Fletcher, Cairo, 1908, especially in Chapter II. on 'The Soil,' by A. Linton, B.Sc. The analyses given show the close relation between the Nile mud and Egyptian soils, the importance of the physical properties of soil as against chemical analysis only is emphasised, and the significance of the presence of soluble salts considered. Much stress is laid

on the physical properties of the soil, in relation to heat, to air, to water, the importance of drainage according as soils are permeable or impermeable, infiltration effects in the two soils and their relative capillarity.

Attention also may be directed to an important series of soil analyses made by Mr F. Hughes in his 'Report on the Manurial Trials on Cotton, 1908,' (*Year-Book Khedivial Agricultural Society*, 1909, pp. 159–194). The points bearing on the soil question on which emphasis is laid are: (1) the irregularity of the quality of the soil; (2) the inconclusiveness of the relation of average yield to chemical composition; (3) the more marked relation of yield to the physical properties of the soil, the proportion of clay (particles under ·002 millimetre), showing that the five best stations gave 34·9 per cent. of clay, and the five lowest 27·2 per cent."

Egyptian soil is mainly Nile deposit. Table 9 gives some typical analyses:—

i. Nile silt taken in August and September; mean of two years.
ii. Good soil from Tanta.
iii. Good soil from Mansura.
iv. Good soil from Etsa in the Fayum.
v. Good soil from Matai (Minia).
vi. and vii. Salted land, bed of Lake Abukir.
viii. Soil with lime, high lying near Abukir.
ix. Well-cultivated soil near Alexandria.
x. Mean of the samples from Kena analysed by Mr Frank Hughes in 1904.

Mr Foaden states that, speaking in round numbers, Nile deposit contains nitrogen, ·10 per cent., phosphoric anhydride, ·20 per cent., potash, ·60 per cent. All the injurious salts in the soils of Egypt are fortunately very soluble in water and can be washed out if treated properly.

Mr Frank Hughes has found from a hundred analyses of soils near Sakha that the proportion of phosphoric acid in the soil decreases rapidly with the distance from the site of the extensive mounds. The reason is that for thousands of years the phosphoric acid has been steadily withdrawn from the soil by the crops; these have been conveyed to the town and consumed there; and the phosphoric acid has been returned in manures and decomposing animal substance chiefly in the neighbourhood of the town, and but sparsely at greater distances. The amount of manure required would vary as the distance, and the difficulty of carrying it would vary in a like proportion; hence the total work to be done would vary as the square of the distance, with the interesting result found by Mr Hughes.

It has been already stated that the physical constitution of the soil is of more importance than the chemical. Owing to the varying conditions of deposition, especially in the basins, the texture of the soil varies extremely from finest to coarsest sand or gravel. The chief effects of the physical character are those on the quantity of water which can be contained.

TABLE 9.—ANALYSIS OF NILE SILT AND EGYPTIAN SOILS.

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. |
|---|---|---|---|---|---|---|---|---|---|---|
| Potash | 0·53 | 0·55 | 0·56 | 0·63 | 0·76 | 0·65 | 1·23 | 0·43 | 0·67 | 0·74 |
| Soda | 0·57 | 0·58 | 0·70 | 0·72 | 0·74 | 0·79 | ... | 0·49 | 0·41 | |
| Lime | 3·07 | 3·38 | 3·28 | 5·53 | 4·47 | 2·08 | 7·73 | 29·52 | 8·03 | 3·34 |
| Magnesia | 2·68 | 2·88 | 2·66 | 2·75 | 2·89 | 1·79 | 0·93 | 1·10 | 0·50 | |
| Manganese oxide | 0·25 | 0·22 | 0·45 | 0·24 | 0·26 | | | | | |
| Oxides of iron and alumina | 25·56 | 23·36 | 24·90 | 20·23 | 24·39 | 18·05 | 21·92 | 8·04 | 23·66 | |
| Phosphoric acid | 0·25 | 0·20 | 0·23 | 0·22 | 0·28 | 0·16 | 0·19 | 0·35 | 0·38 | 0·35 |
| Carbonic acid | 0·73 | 0·67 | 0·85 | 3·03 | 1·10 | 0·19 | 4·75 | 20·15 | 5·59 | 2·69 |
| Chlorine | ... | 0·09 | 0·03 | 0·11 | 0·10 | | | | | |
| Organic matter and combined water | 8·82 | 7·79 | 7·76 | 7·38 | 7·78 | 3·64 | 6·21 | 0·51 | 6·24 | |
| Insoluble matter and sand | 57·54 | 60·28 | 58·58 | 59·18 | 57·23 | 62·23 | 45·81 | 31·51 | 54·27 | 60 |
| Sodium chloride | ... | ... | ... | ... | ... | 8·11 | 8·56 | 1·62 | 0·01 | |
| Iron pyrites | ... | ... | ... | .. | ... | 0·08 | 0·11 | 0·12 | 0·10 | |
| Sulphuric acid | ... | ... | ... | ... | ... | 2·23 | 2·56 | 6·16 | 0·14 | |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | |
| Containing nitrogen | 0·14 | 0·07 | 0·07 | 0·05 | 0·10 | 0·04 | 0·07 | 0·04 | 0·10 | 0·08 |

TABLE 10.—CHEMICAL COMPOSITION OF NILE SILT.

| Ingredients. | Blue Nile. | White Nile. | Atbara. | Roseires. | Sarras. | Aswan. | Cairo. |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | per cent. | per cent. | per cent. | per cent. | per cent. | per cent. | per cent. |
| Silica | 47·59 | 41·96 | 44·09 | 51·74 | 49·07 | 49·47 | 48·88 |
| Oxide of iron | 12·68 | 27·58 | 17·35 | 10·72 | 11·09 | 12·17 | 11·45 |
| Alumina, etc. | 19·47 | 12·30 | 15·66 | 18·31 | 21·44 | 20·30 | 20·58 |
| Titanium | present | present | present | present | present | present | present |
| Oxide of manganese | present | present | present | present | present | present | present |
| Lime | 3·53 | 2·02 | 3·43 | 5·05 | 3·63 | 2·77 | 3·68 |
| Magnesia | 2·73 | 0·84 | 2·01 | 3·23 | 3·14 | 3·04 | 3·36 |
| Potash | 1·77 | 0·85 | 1·22 | 1·70 | 1·24 | 2·33 | 2·27 |
| Soda | 3·11 | 2·78 | 3·30 | 2·98 | 2·61 | 1·82 | 2·02 |
| Phosphoric anhydride | 0·21 | 0·23 | 0·23 | present | 0·19 | present | 0·25 |
| Sulphuric anhydride | 0·06 | 0·06 | 0·06 | ... | 0·10 | ... | 0·07 |
| Carbon dioxide | 0·23 | 0·30 | 0·09 | 0·53 | 0·22 | nil | 0·35 |
| Combined water | 7·04 | 8·66 | 8·40 | 5·15 | 6·63 | 8·10 | 7·09 |
| Organic matter (by differ.) | 1·58 | 2·42 | 4·16 | 0·59 | 0·64 | | |
| | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |

TABLE 11.—PHYSICAL PROPERTIES OF SOME SOILS.

| Sample. | Nature. | Per cent. Composition of Mineral Particles | | | Tenacity. | | Specific Gravity. | Porosity per cent. | Relative Impermeability. | Per cent. Water Capacity | | Shrinkage per cent. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | over 0·5 mm. | under 0·5 mm. | Clay. | Gr. per sq. cm. | Relative. | | | | by Vol. | by Weight. | |
| Faqus | Clay | 1 | 43 | 56 | 546 | 84 | 2·53 | 52 | 184 | 39 | 30 | 38 |
| Soil No. 1 | Loam | ... | 61 | 39 | 83 | 13 | 2·57 | 47 | 23 | 48 | 39·6 | 25 |
| Soil No. 2 | Sandy Loam | ... | 71 | 29 | 42 | 6·5 | 2·61 | 49 | 8 | 48 | 37 7 | 14 |
| Subsoil No. 1 | Clay Loam | ... | 56 | 44 | 83 | 13 | ... | ... | 44 | 48 | 38·5 | 27 |
| Soil No. 3 | Loam | ... | 61 | 39 | 138 | 21 | ... | ... | 50 | 48 | 39·2 | 26 |
| Subsoil No. 3 | Clay | ... | 49 | 51 | 118 | 18 | ... | ... | 25 | 49·5 | 39·3 | |
| Earthnut Soil | Sandy | 5 | 89 | 6 | 6·5 | 1 | 2·63 | 60 | 1 | 36 | 23 | 0 |

Soil may be porous or dense, pervious or impervious. Porosity characterises the capacity of the soil for taking up water, permeability its capacity for allowing water to traverse it. In general, porosity and permeability go together. Sandy soil absorbs about 50 per cent. of its volume of water; clayey soil from 30 to 40 per cent. At a certain depth the pores in the soil are filled with water, and we have ground water; but there is no hard and fast limit between saturated and dry soil. On the contrary, the percentage of water decreases upwards gradually, until near the surface it may be nil. Hence the depth of the ground water is difficult to determine exactly in practice. A tube-well does not exactly give it, for water may be drawn up by capillary attraction above the level of the water in the well to a height depending on the closeness of the grains and to a small extent on the nature of the soil.

Table 11 exhibits the physical constitution of some samples of soil, and Table 12 the effect of capillarity in raising water.

TABLE 12.—RELATIVE CAPILLARITY OF CERTAIN SOILS, DETERMINED BY THE RISE OF WATER IN TUBES AFTER STANDING FOR SOME TIME.

| Sample. | Rise in cm. after standing | | | | | | |
|---|---|---|---|---|---|---|---|
| | 24 hrs. | 48 hrs. | 72 hrs. | 96 hrs. | 120 hrs. | 144 hrs. | 168 hrs. |
| Fakus | 3·0 | 5·5 | 6·8 | 8·0 | 8·9 | 9·7 | 10·7 |
| Soil No. 1 | 42 | 56 | 65 | 72 | 77 | 80 | 84 |
| Soil No. 2 | 44 | 58 | 66 | 73 | 77 | 80 | |
| Soil No. 3 | 36 | 47 | 54 | 60 | 65 | 68 | 73 |
| Subsoil No. 3 | 36 | 48 | 58 | 62 | 67 | 71 | 77 |
| Coarse Sand | 46 | 48 | 50 | 51 | 51 | 51 | |

The finest clay with pores of about 0·004 mm. average diameter will raise water to a height of 7 to 8 metres, and for all practical purposes the height is inversely proportional to the average diameter.

When the interstices of the soil are completely filled with water, the soil is said to be waterlogged. Such soil asphyxiates ordinary crop plants: "the root hairs die from want of air, and the whole plant soon suffers." "The most satisfactory growth is maintained when the amount of water present is not more than 40 to 60 per cent. of what would saturate it" (*Encyclopædia Britannica*, vol. xxv. p. 348*b*).

The water in the soil plays another rôle through its effect on bacteria. These are of two kinds—those which nitrify the soil and so provide plant food, and those whose action is the contrary. The former cannot work in waterlogged soil, but need air; the latter, on the contrary, can only work extensively in waterlogged soils. Waterlogging is thus trebly injurious.

The subsoil in Egypt is, in general, of the same constitution as the soil. Mr A. Lucas* found that the subsoil in the Fayum, so far as the investigation went, contained a greater proportion of injurious salts than the surface soil. The upward movement of the subsoil water under capillary forces carries up the injurious salts from below, and the evaporation of the water leaves them to accumulate at the surface.

When we get down to the deeper subsoil, however, strata of sand, so coarse-grained as almost to pass into gravel, are encountered. These communicate, in many places, directly with the river, and provide a ready supply of water for wells. The water pressure in these strata is increased as the Nile rises, and communicated to considerable distances, causing a slow rise of infiltration water whenever the strata are in communication with the surface through permeable soil.

8. **The Soil of the Sudan.**—A study of the soil of the Gezira, in the Sudan, has been carried out by Dr W. Beam, M.A., M.D., F.I.C., at the Wellcome Laboratories, Khartoum.† The natives recognise two main classes of soil termed by them *bardobe* and *azaza.* The former is best adapted for cultivation, and the most highly esteemed is a variety of it, termed *fuda*, in a good state of tilth; but Dr Beam considers that the difference in cropping power is less due to intrinsic qualities than to differences of rainfall, and the fact that *azaza* has not been much cultivated. *Azaza* prevails in the northern apex, near Khartoum, but near the river flooding causes a heavier soil. Further south rainfall aids decomposition of the silt and formation of clay, up to as much as 60 per cent., and we get *bardobe.* This soil ought to be extremely heavy, but owing to causes not yet thoroughly understood, but of which the intense baking of the soil in the dry season is very probably one, such soils in arid countries are known to be perfectly amenable to cultivation and favourable to plant growth. Dr Beam, however, insists in the strongest terms on the necessity for drainage if this property is to be conserved.

The proportion of soluble salts in the surface soil is less in the well-washed tracts of the Southern Gezira than in the north, but organic matter increases in the opposite direction, owing to greater cultivation towards the south. Phosphates also vary in the same direction as the rainfall, and potash compounds also vary in this direction, but less markedly. The soils in the region considered—Wad Medani to Khartoum—are fairly well supplied with potash and phosphates, but, like most Nile deposit soils, are markedly deficient in organic matter and nitrogen. As a remedy Dr Beam recommends nitrification by the cultivation of leguminous crops after inoculation of the seed with nitrogen-forming bacteria, and in a further note he suggests that beneficial results would follow the use of gypsum

* *A Preliminary Investigation of the Soil and Water of the Fayum.*

† *Fourth Report of the Wellcome Tropical Research Laboratories* (London, 1911), vol. B, p. 34.

as a soil dressing. This use of gypsum has been attended by satisfactory results in Egypt in the hands of M. V. Mosséri.*

Dr Beam's analyses give the following average results for seven samples on each of two lines west of Wad Medani and Kamlin respectively:—

Table 13.—Chemical Analysis, Gezira Soils (First Foot).

| | Wad Medani. | Kamlin. |
|---|---|---|
| Potash soluble in hydrochloric acid | 0·53 | 0·42 |
| Potash insoluble | 0·57 | 0·58 |
| Phosphoric acid | 0·19 | 0·15 |
| Humus | 0·67 | 0·51 |
| Humus nitrogen | 0·015 | 0·011 |
| Total nitrogen | 0·036 | 0·020 |
| Carbonates, expressed as calcium carbonate | 3·5 | 5·7 |
| Water-soluble salts | 0·08 | 0·10 |

The water-soluble salts increase considerably up to four feet below the surface.

In 1904 specimens of Gezira soil were collected from points 10 miles south of Khartoum and from near Khartoum itself. They were analysed by Mr Frank Hughes and reported on by Mr Foaden.

The specimens were numbered as follows:—

(1) Gezira soil from a point 10 miles south of Khartoum near the Blue Nile.

(2) Gezira soil from a point 2 miles south of Khartoum near the White Nile.

(3) White Nile side under cultivation in 1904.

(4) White Nile side below flood level.

(5) Blue Nile side, not so common as (1).

(6) The sandy soil generally within 5 miles of Khartoum.

Nos. 1, 2, 5, and 6 are above high flood level of both Niles.

"The nitrogen and salt were determined in the samples, as received, without drying.

| Nos. | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| Nitrogen | 0·078 | 0·059 | 0·062 | 0·057 | 0·056 | 0·052 | per cent. |
| Common salt | 0·050 | 0·020 | 0·010 | 0·090 | 0·170 | 0·020 | per cent. |

"All contain abundance of carbonate of lime; Nos. 1 and 2 might almost be called calcareous. All gave a strong reaction for phosphoric acid, and there is therefore every reason to believe that they are rich in this ingredient. So far as the texture of the soils is concerned, little can be said except that they differ from those previously examined for Kena

* *Bulletin de l'Institut Egyptien.*

Province, in containing a large amount of coarse sand, 1–3 mm.; which is entirely absent in most Egyptian soils; No. 6 would probably be too light for agricultural purposes in its present condition."

Complete analyses were made of numbers (1) and (2). The results were as follows:—

| | No. 1. | No. 2. |
|---|---|---|
| Silica, etc., insoluble in mineral acid | 74·76 | 73·85 |
| Lime (CaO) | 6·07 | 4·56 |
| Carbonic acid ($CO_2$) | 3·64 | 2·40 |
| Equal to chalk ($CaCO_3$) | 8·27 | 5·46 |
| Potash | 0·23 | 0·34 |
| Phosphoric acid | 0·14 | 0·12 |
| Organic matter | 2·88 | 4·07 |
| Nitrogen | 0·075 | 0·062 |

Calculated on soil dried at 100°.

In Table 14 are given the analyses of different soils from the Taiba cotton farm to the north of Wad Medani made by Dr Beam in 1912.

Dr Beam writes:—

"In general it may be stated that the ultimate physical composition of the samples (*i.e.* the proportion of gravel, sand, silt, and clay) is more or less the same throughout. The differences in yield are found more closely associated with the 'tilth' than with any other factor. Under the circumstances this is to be expected, since in such very heavy soils, good tilth means greater permeability to plant roots and less accumulation of harmful salts. These variations in the texture of the soil over so small an area are not easily explained. They may be due to the presence of sodium carbonate, or, on the other hand, bad texture from any cause may result in the formation of that body. The result in either case is the same; the soil is puddled and less permeable to air and moisture, and consequently to the plant roots.

"Nitrogen and organic matter are low in all the samples, as is usually the case in Egyptian and Sudan soils. The excellent results which, on the whole, have been had in spite of this, are easily explained by the fact that such nitrogen as exists includes a larger proportion in available form than may be expected after a few years, unless steps are taken to renew the supply. In order to establish a *permanent* system of cultivation the nitrogen removed by the crops from year to year should be returned to it. This is best done not in the form of nitrate fertiliser, but by a system of rotation with a leguminous crop, a portion of the green crop being turned into the soil. By this means not only will the nitrogen be secured, but, what is quite as essential, the organic matter of the plants will aid in keeping the soil permeable. Further, the liberation of carbonic and other acids by the decomposition of this organic matter is a necessary condition to the solution of the mineral plant food—phosphorus, potassium, etc. Wherever possible, organic matter should be ploughed into the soil. If, for instance, wheat is one of the crops in the rotation, it would be advisable to turn in as much of the stalk as possible. Even if these stalks are quite dry, they will still benefit the soil largely and aid in bringing it to the condition of texture, the 'tilth' which is essential to good yields and the best products."

TABLE 14.—SOILS FROM TAIBA FARM.

| Serial No. | 2438 | 2439 | 2440 | 2441 | 2450 | 2451 | 2452 | 2453 | 2462 | 2463 | 2464 | 2465 | 2466 | 2467 | 2468 | 2469 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Owner of Land | Raslan. | | | | Aisa Mohd. Bageil. | | | | Boutros Herimina. | | | | Diab Gadalla. | | | |
| Marks | *1a.* 1st ft. | *1b.* 2nd ft. | *1c.* 3rd ft. | *1d.* 4th ft. | *4a.* 1st ft. | *4b.* 2nd ft. | *4c.* 3rd ft. | *4d.* 4th ft. | *7a.* 1st ft. | *7b.* 2nd ft. | *7c.* 3rd ft. | *7d.* 4th ft. | *8a.* 1st ft. | *8b.* 2nd ft. | *8c.* 3rd ft. | *8d.* 4th ft. |
| Stones and gravel | 4·9 | 1·6 | | | 3·1 | 1·7 | | | 3·1 | 2·0 | | | 3·3 | 1·4 | | |
| Coarse sand | 9·7 | 6·3 | | | 9·1 | 6·6 | | | 7·8 | 7·7 | | | 10·3 | 8·3 | | |
| Fine sand | 26·9 | 23·4 | | | 22·8 | 21·0 | | | 27·8 | 22·1 | | | 21·4 | 22·0 | | |
| Silt | 15·2 | 15·7 | | | 14·9 | 15·2 | | | 13·2 | 14·8 | | | 15·1 | 15·0 | | |
| Clay | 53·2 | 54·6 | | | 53·2 | 57·2 | | | 51·2 | 55·4 | | | 53·2 | 54·7 | | |
| Nitrogen | 0·023 | | | | 0·032 | | | | 0·022 | | | | 0·018 | | | |
| Phosphate ($P_2O_5$) | 0·119 | | | | 0·130 | | | | 0·113 | | | | 0·111 | | | |
| Potash ($K_2O$) | 0·59 | | | | 0·58 | | | | 0·60 | | | | 0·65 | | | |
| Soluble salts | 0·07 | 0·08 | 0·18 | 0·42 | 0·07 | 0·08 | 0·15 | 0·23 | 0·08 | 0·10 | 0·12 | 0·15 | 0·12 | 0·11 | 0·30 | 0·52 |
| Sodium carbonate | marked amount | | | | traces only | | | | traces only | | | | marked amount | | | |
| Humus | 0·36 | | | | 0·44 | | | | 0·35 | | | | 0·38 | | | |
| | Cotton plants only about 2 feet high. | | | | Best growth on the farm. | | | | Very good growth. Plants 5 feet and over. | | | | Poorest growth on the farm. | | | |
| | *Unfavourable.* Pronounced puddled state of soil, probably due to the presence of sodium carbonate, which also acts as a plant poison. | | | | *Favourable.* Good tilth down to and including the 4th foot. Greater penetration of roots. Highest proportion of organic matter (humus) and nitrogen. Low proportion of salt even in fourth foot. | | | | *Favourable* Good tilth and penetrability. Very small amount of salt even in fourth foot. | | | | *Unfavourable.* Poor tilth and slightly lower nitrogen. Marked amount of sodium carbonate. | | | |

The following analyses were made by Dr Beam in 1912 of the amount of nitrogen in soils on the Nile berm near Atbara on the main Nile:—

| | Nitrogen per cent. |
|---|---|
| (1) Nile deposit near the river . . . . . . . . | ·08 |
| (2) Soil deposited by streams from the deserts and above flood level | ·025 |
| (3) ,, ,, ,, ,, ,, ,, ,, | ·03 |
| (4) ,, ,, ,, ,, ,, ,, ,, | ·02 |
| (5) Land recently under beans . . . . . . . . | ·04 |

A sample of the soil of the Sudan above the flood level of the White Nile at Renk was analysed by Dr Beam, with the following result. The land had produced a light cotton crop with the aid of the rainfall.

Mechanical Analysis—

| | |
|---|---|
| Stones and gravel above 2 mm. . . . | 0·5 per cent. |

*Analysis of Fine Soil.*

| | |
|---|---|
| Coarse sand (2 mm. to 0·2 mm.) . . . | 5·2 per cent. |
| Fine sand (0·2 mm. to 0·02 mm.) . . . | 5·4 ,, |
| Silt (0·02 mm. to 0·002 mm.) . . . . | 10·9 ,, |
| Clay (0·002 mm. and below) . . . . | 78·5 ,, |

Chemical Analysis—

| | |
|---|---|
| Potash soluble in hydrochloric acid ($K_2O$) . | 0·46 per cent. |
| Phosphates ($P_2O_5$) . . . . . . | 0·046 ,, |
| Nitrogen (N) . . . . . . . | 0·032 ,, |
| Soluble salts . . . . . . . | 0·05 ,, |

These figures indicate an extremely heavy soil and one deficient in phosphates. If the sample is fairly representative of the district, the soil would soon require the addition of a phosphatic fertiliser. Nitrogen is also low. The effect of these two conditions would not of course be likely to be felt this first year of cultivation.

9. **Nile Water.**—The information on this head has been ably epitomised by Mr A. Lucas in his *Chemistry of the River Nile,* from which we quote the following:—

"The chemical aspect of the Nile may be conveniently considered under the two following heads, namely:—

(1) The amount and nature of the matter in suspension.

(2) The amount and nature of the matter in solution.

*Matter in Suspension.*—A detailed account of all the most important determinations that have been made of the amount of suspended matter in the river, together with a critical examination and discussion of the results obtained, is to be found in *The Physiography of the River Nile and its Basin.* Since the publication of Captain Lyons' book, however, further work has been done, and the following tables epitomise most of the results that are at present available, omitting only those from isolated samples.

TABLE 15.—MATTER IN SUSPENSION IN THE NILE AT VARIOUS PLACES.
(Grams per cubic metre—parts per million.)

| Month. | Blue Nile. | | | | White Nile. | | | | Atbara. | | Sarras. | | Naga Hammadi. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1902–3. | 1904–5. | 1906. | 1907. | 1902–3. | 1904–5. | 1906. | 1907. | 1902. | 1907. | 1905. | 1906. | 1903. | 1904. | 1905. |
| | Survey Dept. | Beam. | | | Survey Dept. | Beam. | | | Survey Dept. | Beam. | Survey Dept. | | Naus. | | |
| January | 30 | 7 | 8 | 2 | 83 | 71 | 62 | 86 | ... | ... | ... | ... | ... | 74 | 42 |
| February | 30 | 4 | 12 | 5 | 59 | 67 | 56 | 70 | ... | ... | ... | ... | ... | 39 | 30 |
| March | 37 | 9 | 6 | 4 | 51 | 55 | 50 | 59 | ... | ... | ... | ... | ... | 44 | |
| April | 45 | 7 | 8 | 11 | 38 | 56 | 49 | 52 | | | | | | | |
| May | 74 | 7 | 29 | 5 | 62 | 52 | 49 | 78 | ... | ... | ... | ... | ... | 36 | 34 |
| June | 201 | 7 | 271 | ... | 118 | 49 | 81 | ... | ... | 4 | 14 | ... | ... | 70 | 31 |
| July | 400 | 472 | 1004 | ... | 183 | 76 | 47 | ... | ... | 1670 | 45 | 334 | ... | 82 | 36 |
| August | 958 | 994 | 1964 | ... | 276 | 143 | 167 | ... | 4758 | 2228 | 659 | 2107 | 799 | 1096 | 673 |
| September | 921 | ... | 758 | ... | 143 | 27 | 69 | ... | 567 | 833 | 633 | 1559 | 1154 | 764 | 1454 |
| October | 239 | 110 | 280 | ... | 60 | 32 | 28 | ... | ... | 103 | ... | 830 | 634 | 401 | 784 |
| November | 92 | 58 | 109 | ... | 105 | 83 | 60 | ... | ... | ... | ... | ... | 290 | 155 | |
| December | 36 | 19 | 22 | ... | 67 | 74 | 48 | ... | ... | ... | ... | ... | 141 | 67 | |
| Maximum | 1573 | 994 | 1964 | ... | 428 | 143 | 167 | ... | 4758 | 3576 | 1482 | 3188 | 1436 | 1418 | 1774 |

TABLE 16.—MATTER IN SUSPENSION IN THE NILE AT CAIRO.
(Grams per cubic metre—parts per million.) (See page 236.)

| Month. | 1849-50. Magdali. | 1874-5. Letheby. | 1887. Mathey. | 1888-9. Pollard. | 1891. Richmond. | 1897. Mackenzie. | 1896. Mackenzie. | 1898. Mackenzie. | 1899. Mackenzie. | 1906. Burns. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 224 | 167 | 165 | 132 | ... | 290 | 490 | ... | ... | 135 |
| February | 226 | 126 | 132 | 95 | ... | 250 | 270 | ... | ... | 88 |
| March | 146 | 53 | 73 | 55 | 38 | 200 | 190 | ... | ... | 52 |
| April | ... | 66 | 50 | 50 | 45 | 160 | 140 | ... | ... | 46 |
| May | 114 | 48 | 50 | 25 | 14 | 130 | 140 | ... | ... | 41 |
| June | 46 | 69 | 143 | 28 | 66 | 170 | 130 | ... | ... | 39 |
| July | 106 | 178 | 182 | 37 | 313 | 100 | 110 | 201 | 131 | 29 |
| August | 5474 | 1492 | 1235 | 1631 | 1500 | 1000 | 1740 | 1862 | 1122 | 509 |
| September | 5120 | 543 | 553 | 1974 | 1532 | 1660 | 1630 | 1288 | 1202 | 1270 |
| October | 1925 | 378 | 390 | 1056 | ... | 1350 | 1000 | 905 | 634 | 673 |
| November | 1236 | 344 | 334 | 648 | ... | 900 | 600 | 580 | 328 | 303 |
| December | ... | 289 | 291 | 235 | ... | 630 | 350 | 429 | 138 | 195 |

From the foregoing tables it will be seen what considerable variations take place in the amount of suspended matter in the river both at different places and at different seasons, and also from one year to another. It will be noticed, too, what a small part of the silt comes from the White Nile, the bulk being due to the Blue Nile and the Atbara.

The flood water of the Nile in Egypt has always a reddish-brown appearance, due to the colour of the silt it carries, and is spoken of as the 'red' water. Immediately before the flood, however, the water is green in colour and has a very objectionable smell, somewhat like that of decaying vegetation, becoming more marked after boiling or distillation. This green colour is due to the presence of chlorophyll-containing algæ brought down in immense quantities from the White Nile, and the smell is probably derived from the putrefaction of the dead algæ and the liberation of the essential oil which they contain.

No detailed investigation of these algæ has yet been made, but Kaufmann states that *Synedra acus Grunov*, *variatio delicatissima*; *Anahœna variabilis*; and *Aphanizomenon Kaufmanni* were present in the green water of 1895 and 1896.

The origin of the green water has been discussed by Captain Lyons in his *Physiography of the River Nile.*

Dr Schweinfurth has suggested that this growth of algæ may take place wherever the low supply water of the Nile is nearly stagnant.

A certain amount of algal growth takes place in the Aswan Reservoir. Thus Willcocks writes: 'Upstream of the Aswan dam in June 1903, the water was extraordinarily green and exceedingly objectionable.' As the water level of the reservoir is lowered, these algæ, which are chiefly at the surface of the water, are left adhering to the rocks, and die, decay, and bleach to a white colour, with the

result that a disfiguring white band about 30 centimetres broad appears on all rocks, marking the height at which the water stands when the reservoir is full. Some specimens of these dead algæ from the rocks at Shellal were taken by the writer in November 1907, but on examination they proved to be so dried up that it was impossible to recognise them with any degree of certainty: they were, however, filamentous algæ, chiefly of one kind which resembled very much the *Aphanizomenon Kaufmanni* determined by Schmiedle.

In connection with the suspended matter in the river, mention should also be made of the bacteria, since these too are in suspension.

The sediment in suspension in the Nile is very finely divided, and would practically all be classed as silt and clay in any scheme of mechanical analysis. Two samples were kindly examined for the writer by Mr A. D. Hall, Director of the Rothamsted Experimental Station, one being the sediment from a cubic metre of water taken directly from the river in November 1905, and the other a sample of mud from the channel leading to the sedimentation basins of the Giza waterworks. The latter naturally consisted of the coarser material only, since the finer particles are not deposited in the channel but pass on into the basins. The results of the analyses are given below:—

TABLE 17.—MECHANICAL ANALYSES OF NILE SILT. By A. D. HALL, Director, Rothamsted Experimental Station.

| | Water from River, sedimented in Special Tank. | | Mud from Channel leading to Sedimentation Basins of Giza Water Service. | |
|---|---|---|---|---|
| | Dried at 100°. Per cent. | Ignited. Per cent. | Dried at 100°. Per cent. | Ignited. Per cent. |
| Retained by sieve above 0·2 mm. | ... | ... | ... | ... |
| 1st Sediment 0·2–0·04 mm. | 0·60 | 0·58 | 10·25 | 10·05 |
| 2nd " 0·04–0·01 mm. | 8·17 | 7·82 | 38·02 | 36·90 |
| 3rd " 0·01–0·004 mm. | 17·53 | 16·62 | 10·33 | 9·54 |
| 4th " 0·004–0·002 mm. | 10·40 | 9·15 | 7·08 | 5·85 |
| Clay < 0·002 mm. | 50·24 | 42·92 | 26·64 | 22·33 |
| Loss on solution | 2·34 | 2·34 | 5·27 | 5·27 |
| Moisture | 8·58 | 8·58 | 4·64 | 4·64 |
| Loss on ignition | ... | 10·27 | ... | 7·06 |
| | 97·86 | 98·28 | 102·23 | 101·64 |

It will be seen that about 50 per cent. of the silt from the river consisted of particles having a diameter less than 0·002 mm. Commenting on these results, Mr Hall says the silt taken direct from the river 'in mass would be a sticky tenacious clay far heavier and more difficult to work than any soil we meet with in this country, being only comparable to some of the London clay subsoils.'

According to some mechanical analyses by Means the proportion of 'clay'

(*i.e.* particles having a diameter from 0·005 to 0·0001 mm.) found in Egyptian soils was in one or two cases as high as 75 per cent., and in only six samples out of twenty-one was it less than 40 per cent. Clay soils in fact occur very extensively in Egypt, and, although the material has all the physical characteristics of kaolin, is very sticky and plastic when wet, cracks and becomes hard when dry, and has been used for brick-making from the earliest times of which there are any records, yet it is not necessarily hydrated silicate of alumina, or even largely so, since it is now generally recognised that the so-called 'clay' properties depend upon the fineness rather than upon the nature of the particles.

The valuable fertilising ingredients in the Nile mud are phosphoric acid, potash, and nitrogen, the latter being contained in the organic matter present.

The phosphoric acid varies from 0·2 per cent. up to 0·3 per cent.

The potash varies from 0·5 per cent. to 2·3 per cent.; it is noteworthy that all Mackenzie's results are about 0·5 per cent.

The organic matter varies from 0·6 per cent. up to 15·0 per cent. In all the analyses, however, except those of the Survey Department, it would appear as though that which is returned as organic matter must also include the combined water present.

As a brief summary of the manurial value of Nile mud the following statements may be quoted:—

'Nile mud supplies sufficient quantities of phosphoric acid and potash for the growth of fair crops of cotton, wheat, barley, maize, beans, and potatoes, but does not do so for sugar cane, clover, and lucerne.

'Nile mud does not supply a sufficient amount of nitrogen for the use of nitrogen-consuming crops.'

One of the important features brought out by the table is that the White Nile silt is the poorest in silica, alumina, lime, magnesia, and potash, and the richest in iron.

The small amount of potash in the White Nile silt indicates only a small amount of felspar. The White Nile, however, contains more potash in solution than is found in the Blue Nile.

Another feature shown by the analyses is that the nearer one approaches Abyssinia the greater is the silica content of the silt, and the higher the lime and carbon dioxide.

The high potash in most of the samples except that from the White Nile indicates undecomposed felspar or possibly Muscovite mica.

The samples from Sarras, Aswan, and Cairo, do not show any very marked differences of composition.

*Matter in Solution.*—Not only does the suspended matter in the river vary considerably in amount at different times of the year, but the proportion of soluble matter also varies according to the season, being highest when the river is at its lowest ebb and gradually decreasing as the river rises, until the minimum is reached when the Nile is in full flood, after which the proportion gradually rises again as the river falls.

The soluble matter not only varies from month to month, but also from year to year.

The total soluble matter and chlorine in Nile water are shown in the following tables:—

TABLE 18.—TOTAL SOLUBLE MATTER IN NILE WATER.
(Grams per cubic metre—parts per million.)

| Month. | Blue Nile. | | | White Nile. | | | Nile at Sarras. | Nile at Cairo. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1904-5. | 1906. | 1907. | 1904-5. | 1906. | 1907. | 1906. | 1874-5. | 1888-9. | 1891. | 1905. | 1906. | 1906. | 1907. |
| | Beam. | | | Beam. | | | Survey Dept. | Letheby. | Pollard. | Richmond. | Survey Dept. | | Burns. | Survey Dept. |
| January | 1905. 115 | 166 | 120 | 1905. 160 | 191 | 127 | ... | 1875. 145 | 1889. 136 | ... | 170 | 157 | 148 | 150 |
| February | ... | ... | 137 | ... | ... | 153 | ... | 147 | 163 | ... | 193 | 163 | 145 | 149 |
| March | 120 | 135 | 129 | 178 | 190 | 163 | ... | 178 | 199 | 180 | 207 | 182 | 171 | 170 |
| April | ... | 148 | 131 | ... | 205 | 183 | ... | 182 | 244 | 231 | 230 | 211 | 189 | 208 |
| May | 130 | 141 | 154 | 196 | 217 | 169 | ... | 205 | 277 | 196 | 240 | 215 | 198 | 217 |
| June | 135 | 119 | ... | 199 | 190 | ... | ... | 1874. 203 | 1888. 260 | 158 | 230 | 217 | 220 | 231 |
| July | ... | 97 | ... | ... | 164 | ... | 168 | 164 | 263 | 172 | 206 | 215 | 215 | 207 |
| August | ... | 135 | ... | ... | 162 | ... | 144 | 166 | 173 | 162 | 180 | 170 | 235 | 172 |
| September | ... | 109 | ... | ... | 135 | ... | 141 | 194 | 133 | 131 | 140 | 130 | 146 | 137 |
| October | 110 | 106 | ... | 140 | 112 | ... | 130 | 159 | 124 | ... | 132 | 130 | 139 | 127 |
| November | 1904. 105 | 130 | 1904. ... | 165 | 176 | ... | ... | 150 | 131 | ... | 146 | 140 | 145 | 139 |
| December | 109 | 110 | ... | 163 | 122 | ... | ... | 136 | 131 | ... | 150 | 133 | 133 | 145 |
| Minimum | ... | 97 | ... | ... | 112 | ... | 124 | 136 | 122 | 131 | 125 | 124 | 133 | 120 |
| Maximum | ... | 166 | ... | ... | 217 | ... | 196 | 205 | 292 | 231 | 260 | 239 | 235 | 238 |

1874-5 Monthly samples.
1888-9 Fortnightly samples.
1905-6-7 (Survey Dept.) Monthly means from weekly samples.
1906 (Burns) Monthly samples.

TABLE 19.—CHLORINE IN NILE WATER.
(Grams per cubic metre—parts per million.)

| Month. | Atbara. | Blue Nile. | | | White Nile. | | | Nile at Sarras. | Nile at Cairo. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1907. | 1904–5. | 1906. | 1907. | 1904–5. | 1906. | 1907. | 1906. | 1874–5. | 1888–9. | 1891. | 1905. | 1906. | 1906. | 1907. |
| | Beam. | Beam. | | | Beam. | | | Survey Dept. | Letheby. | Pollard. | Richmond. | Survey. Dept. | | Burns. | Survey Dept. |
| | | 1905. | | | 1905. | | | | 1875. | 1889. | | | | | |
| January . . | ... | 1·5 | 1·7 | 2·0 | 5·4 | 5·5 | 4·7 | ... | 2·4 | 4·3 | ... | 6·7 | 7·6 | 5·6 | 6·6 |
| February . . | ... | ... | 1·8 | 2·1 | ... | 8·3 | 6·6 | ... | 2·5 | 9·2 | ... | 9·6 | 11·0 | 7·9 | 8·5 |
| March . . | ... | 2·7 | 2·0 | 2·1 | 9·2 | 11·0 | 7·8 | ... | 6·1 | 9·6 | 10·1 | 14·7 | 14·0 | 12·9 | 11·5 |
| April . . | ... | ... | 3·0 | 3·3 | ... | 15·1 | 9·7 | ... | 9·2 | 24·2 | 20 9 | 20·1 | 19·2 | 14·1 | 18·3 |
| May . . | ... | 4·5 | 2·2 | 3·8 | 11·4 | 13·7 | 11·5 | ... | 17·4 | 32·1 | 29·1 | 24·3 | 19·9 | 15·5 | 18·4 |
| | | | | | | | | | 1874. | 1888. | | | | | |
| June . . | ... | 7·7 | 2·1 | ... | 11·5 | 12·3 | ... | ... | 16·4 | 35·7 | 14 1 | 23·7 | 20·1 | 16·2 | 20·0 |
| July . . | 3·2 | ... | 1·9 | ... | ... | 9·5 | ... | 9·4 | 8·5 | 24·6 | 6·4 | 20·5 | 19 4 | 17·1 | 17·4 |
| August . . | 3·0 | ... | 1 9 | ... | ... | 4·3 | ... | 4·5 | 6·3 | 10·3 | 6·6 | 12·2 | 9·2 | 14·0 | 10·1 |
| September . | 3·0 | ... | 1 7 | .. | ... | 7·9 | ... | 3·1 | 2·1 | 3·2 | 5·6 | 3·6 | 3·6 | 3·6 | 4 1 |
| October . . | ... | 2·6 | 1 5 | ... | 5·6 | 4·5 | ... | 3·2 | 4·9 | 2·7 | ... | 3·7 | 3·7 | 3·2 | 3·8 |
| | | 1904. | | | 1904. | | | | | | | | | | |
| November . | ... | 1·6 | 1·8 | ... | 4·8 | 3·8 | ... | ... | 2·1 | 3·0 | ... | 5·0 | 4·6 | 4 3 | 5·4 |
| December . | ... | 1·6 | 2·0 | ... | 4·6 | 3·8 | ... | ... | 2·8 | 2·9 | ... | 6·8 | 5·0 | 3·7 | 7·6 |
| Minimum . | 1·91 | ... | 1·5 | ... | ... | 3·8 | ... | 2·7 | 2·1 | 2·4 | 5·6 | 2·5 | 3·2 | 3·2 | 3·3 |
| Maximum . | 4·34 | ... | 3·0 | .. | ... | 15·1 | ... | 12·3 | 17·4 | 40·0 | 29·1 | 26·0 | 24·5 | 17·1 | 20·6 |

1874–5 Monthly samples.
1888–9 Fortnightly samples.

1905–6–7 (Survey Department) Monthly means from weekly samples.
1906 (Burns) Monthly samples.

In addition to the total soluble salts and chlorine, the organic matter, as estimated by the albuminoid ammonia and oxygen absorbed, and also the products of its oxidation, namely ammonia, nitrous and nitric acids, have also been determined.

The Survey Department analyses of samples taken at Cairo during 1905–6–7 are appended, as also Beam's analyses of the Blue and White Nile water for 1904–5 and 1906:—

TABLE 20.—UNFILTERED NILE WATER (CAIRO).*
(Grams per cubic metre—parts per million.)

| Month. | Free Ammonia. | | | Albuminoid Ammonia. | | | Oxygen absorbed.† | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1905. | 1906. | 1907. | 1905. | 1906. | 1907. | 1905. | 1906. | 1907. |
| January . | 0·019 | 0·031 | 0·008 | 0·385 | 0·315 | 0·232 | 3·00 | 2·90 | 2·82 |
| February . | 0·020 | 0·021 | 0·011 | 0·353 | 0·338 | 0·299 | 2·71 | 3·30 | 3·06 |
| March . . | 0·018 | 0·024 | 0·022 | 0·298 | 0·325 | 0·307 | 3·27 | 2·79 | 2·90 |
| April . . | 0·023 | 0·023 | 0·010 | 0·281 | 0·408 | 0·291 | 2·55 | 2·40 | 2·62 |
| May . . | 0·036 | 0·041 | 0·013 | 0·391 | 0·342 | 0·299 | 2·39 | 2·75 | 2·55 |
| June . . | 0·063 | 0·030 | 0·016 | 0·590 | 0·407 | 0·401 | 2·91 | 3·22 | 2·71 |
| July . . | 0·135 | 0·101 | 0·138 | 0·850 | 0·488 | 0·746 | 4·02 | 3·71 | 4·21 |
| August . | 0·063 | 0·049 | 0·015 | 0·888 | 0·802 | 0·656 | 5·31 | 12·83 | 7·30 |
| September . | 0·081 | 0·058 | 0·020 | 1·670 | 0·992 | 0·914 | 15·21 | 14·25 | 12·50 |
| October . | 0·041 | 0·026 | 0·009 | 0·982 | 0·618 | 0·565 | 9·13 | 7·42 | 8·40 |
| November . | 0·025 | 0·023 | 0·013 | 0·521 | 0·407 | 0·450 | 5·08 | 5·02 | 4·44 |
| December . | 0·041 | 0·010 | 0·042 | 0·423 | 0·289 | 0·386 | 2·92 | 3·17 | 2·83 |
| Minimum. | 0·010 | 0·005 | 0·005 | 0·185 | 0·212 | 0·202 | 2·05 | 1·90 | 2·15 |
| Maximum. | 0·225 | 0·325 | 0·265 | 2·160 | 1·280 | 1·100 | 20·70 | 21·82 | 12·90 |

* Monthly means from weekly samples (Survey Department Laboratories).
† In acid solution after boiling for ten minutes.

[TABLE.

TABLE 21.—NILE WATER (SUDAN).*
(Grams per cubic metre—parts per million.)

| Month. | Free Ammonia. | | | | Albuminoid Ammonia. | | | | Oxygen absorbed.† | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Blue Nile. | | White Nile. | | Blue Nile. | | White Nile. | | Blue Nile. | | White Nile. | |
| | 1904–5. | 1906. | 1904–5. | 1906. | 1904–5. | 1906. | 1904–5. | 1906. | 1904–5. | 1906. | 1904–5. | 1906. |
| January | 0·006 | ... | 0·020 | ... | 0·075 | ... | 0·340 | ... | 0·80 | 1·75 | 6·15 | 5·49 |
| February | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| March | 0·020 | 0·005 | 0·020 | 0·003 | 0·160 | 0·110 | 0·230 | 0·240 | 0·65 | 2·35 | 8·53 | 5·75 |
| April | ... | 0·003 | ... | 0·008 | ... | 0·166 | ... | 0·392 | ... | 2·45 | ... | 5·75 |
| May | 0·030 | 0·027 | 0·024 | 0·010 | 0·180 | 0·259 | 0·260 | 0·320 | 0·84 | 3·57 | 8·00 | 6·20 |
| June | 0·032 | 0·011 | 0·023 | 0·010 | 0·198 | 0·396 | 0·300 | 0·458 | 0·89 | 4·50 | 8·70 | 6·15 |
| July | ... | 0·029 | ... | 0·019 | ... | 1·114 | ... | 0·288 | ... | 42·25 | ... | 5·70 |
| August | ... | 0·034 | ... | 0·020 | ... | 2·256 | ... | 0·345 | ... | 56·00 | ... | 9·77 |
| September | ... | 0·006 | ... | 0·009 | ... | 1·232 | ... | 0·161 | ... | 15·48 | ... | 4·79 |
| October | 0·081 | 0·008 | 0·016 | 0·015 | 0·169 | 0·260 | 0·260 | 0·190 | 3·65 | 9·48 | 6·00 | 5·60 |
| November | 0·015 | 0·007 | 0·019 | 0·010 | 0·138 | 0·168 | 0·284 | 0·333 | 2·20 | 3·12 | 6·40 | 5·43 |
| December | trace | 0·005 | 0·012 | 0·008 | 0·114 | 0·172 | 0·272 | 0·269 | 1·70 | 1·67 | 6·76 | 5·00 |
| Minimum | ... | 0·003 | ... | 0·003 | ... | 0·110 | ... | 0·161 | ... | 1·67 | ... | 4·79 |
| Maximum | ... | 0·034 | ... | 0·020 | ... | 2·256 | ... | 0·458 | ... | 56·00 | ... | 9·77 |

* Monthly samples (Dr Beam).
† In acid solution after boiling for ten minutes.

The following table shows the free ammonia and the albuminoid ammonia in filtered Nile water, as well as the amount of oxygen required to oxidise the organic matter present.

TABLE 22.—FILTERED NILE WATER.*
(Grams per cubic metre—parts per million.)

| Month. | Free Ammonia. | | | Albuminoid Ammonia. | | | Oxygen absorbed.† | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1905. | 1906. | 1907. | 1905. | 1906. | 1907. | 1905. | 1906. | 1907. |
| January | 0·012 | 0·043 | 0·004 | 0·148 | 0·121 | 0·075 | 1·59 | 1·37 | 1·29 |
| February | 0·062 | 0·012 | 0·009 | 0·154 | 0·177 | 0·116 | 1·86 | 1·66 | 1·64 |
| March | 0·033 | 0·012 | 0·013 | 0·152 | 0·135 | 0·137 | 2·54 | 1·67 | 1·67 |
| April | 0·012 | 0·010 | 0·008 | 0·127 | 0·177 | 0·143 | 1·61 | 1·75 | 1·58 |
| May | 0·008 | 0·022 | 0·009 | 0·135 | 0·188 | 0·161 | 1·50 | 1·77 | 1·55 |
| June | 0·012 | 0·017 | 0·007 | 0·150 | 0·166 | 0·148 | 1·43 | 1·86 | 1·57 |
| July | 0·038 | 0·014 | 0·012 | 0·233 | 0·172 | 0·192 | 2·09 | 2·14 | 1·72 |
| August | 0·024 | 0·010 | 0·006 | 0·227 | 0·116 | 0·101 | 2·02 | 2·29 | 1·46 |
| September | 0·009 | 0·012 | 0·004 | 0·106 | 0·080 | 0·054 | 1·19 | 1·38 | 1·17 |
| October | 0·018 | 0·015 | 0·006 | 0·101 | 0·072 | 0·051 | 1·10 | 1·03 | 1·14 |
| November | 0·008 | 0·008 | 0·007 | 0·082 | 0·078 | 0·122 | 0·92 | 1·17 | 1·25 |
| December | 0·014 | 0·008 | 0·011 | 0·111 | 0·071 | 0·210 | 1·19 | 0·98 | 1·16 |
| Minimum. | 0·008 | 0·003 | nil | 0·082 | 0·060 | 0·043 | 0·92 | 0·42 | 1·00 |
| Maximum. | 0·062 | 0·085 | 0·025 | 0·233 | 0·240 | 0·435 | 2·54 | 2·67 | 1·95 |

* Monthly means from weekly samples taken at Cairo (Survey Department Laboratories).
† In acid solution after boiling for ten minutes.

The nature of the mineral matter in solution in Nile water is epitomised in Table 23."

The amount of matter in suspension and its nature depend on the turbulence of the water, that is, on the relative velocity of the various parts of the current. It may be shown * that the turbulence is proportional to the bottom velocity and to the hydraulic mean depth. The silt content will therefore depend on the same variables. But since the product of the mean depth by the mean velocity is roughly proportional to the discharge, the silt content per cubic metre should be roughly proportional to the discharge, and in point of fact we find that on the Blue Nile and Main Nile,

on the rising stage $S = 0{\cdot}18D$, and
on the falling stage $S = 0{\cdot}11D$,

where S is the number of grams per cubic metre, and D is the discharge

* See *Hydraulique générale*, par A. Boulanger, Paris, 1909, where the mathematical work of Boussinesq is summarised.

TABLE 23.—COMPOSITION OF MINERAL MATTER IN SOLUTION IN NILE WATER.
(Grams per cubic metre—parts per million.)

| Ingredients. | Victoria Nyanza. | Albert Nile. Survey Dept. | Bahr Zaraf. Survey Dept. | Sobat. Survey Dept. | White Nile. Beam. | | | | Blue Nile. Beam. | | | | Nile at Cairo. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Min | | Max. | | Min. | | Max. | | Letheby. 1874-5. | | Tidy. | | Mathey. 1887. | | Burns. 1906. | | Surv. Dept. 1905-6-7. | |
| | | 1902. | 1902. | 1902. | 1904-5 | 1906. | 1904-5 | 1906. | 1904-5 | 1906. | 1904-5 | 1906. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| Total soluble salts | 234·0 | 164·0 | 220·0 | 70·0 | 140·0 | 112·0 | 199·0 | 216·5 | 103·0 | 96·8 | 165·0 | 166·1 | 136·1 | 204·7 | 136·1 | 204·7 | ... | ... | 132·5 | 235·0 | 124·0 | 260·0 |
| Silica | 10·1 | 28·7 | 38·3 | 20·6 | 21·0 | 6·4 | 25·0 | 49·2 | 23·5 | 14·4 | 26·0 | 30·4 | 6·7 | 18·4 | ... | ... | ... | ... | 17·5 | 34·5 | 10·5 | 18·0* |
| Oxide of iron and alumina | 2·6 | 4·1 | 4·6 | 1·9 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1·6 | 1·6* |
| Lime | 13·0 | 15·7 | 25·3 | 12·8 | 13·1 | 14·5 | 29·3 | 29·5 | 25·8 | 19·3 | 35·7 | 36·1 | 23·1 | 51·8 | 29·3 | 62·1 | 41·7 | 46·7 | 26·7 | 40·2 | 39·0 | 39·9* |
| Magnesia | 11·3 | 11·2 | 17·4 | 5·3 | 5·8 | 10·6 | 10·8 | 22·0 | 7·2 | 7·9 | 9·7 | 16·6 | 4·8 | 16·2 | 4·6 | 15·5 | ... | ... | 10·8 | 16·9 | 10·4 | 14·1* |
| Potash | ... | ... | ... | ... | 9·0 | 5·5 | 21·2 | 26·5 | 1·7 | 2·3 | 2·3 | 3·4 | 4·0 | 41·2 | ... | ... | 8·4 | 21·0 | 3·9 | 24·6 | | |
| Soda | 45·1 | ... | ... | ... | 17·1 | 13·9 | 49·7 | 49·9 | 7·5 | 2·5 | 10·5 | 17·0 | 3·0 | 13·0 | ... | ... | ... | ... | 17·8 | 49·5 | | |
| Phosphoric acid | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | trace | trace | ... | ... | trace | trace | ... | ... | 3·0 | 3·5 |
| Sulphuric acid | 2·2 | trace | trace | trace | nil | nil | 1·0 | 4·5† | 3·9 | 1·8 | 6·3 | 9·6 | 17·6 | 29·3 | 17·0 | 26·3 | 1·4 | 3·2 | 4·1 | 8·9 | 8·6 | 13·1 |
| Nitric acid | ... | trace | trace | trace | 0·07 | 0·03 | 0·10 | 0·29 | 0·02 | 0·03 | 0·05 | 0·71 | trace | trace | ... | ... | ... | ... | ... | ... | nil | 0·7 |
| Carbonic acid | 41·1 | ... | ... | ... | 36·3 | 36·4 | 68·9 | 77·6 | 29·5 | 28·3 | 43·9 | 43·2 | ... | ... | ... | ... | 30·4 | 41·0 | | | | |
| Carbonic acid and loss | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 32·7 | 49·4 | | | | | | | | |
| Chlorine | 12·3 | 10·4 | 7·0 | 3·5 | 3·6 | 3·8 | 11·5 | 15·1 | 1·5 | 1·7 | 7·7 | 3·0 | 2·1 | 17·4 | 2·1 | 19·9 | ... | ... | 3·2 | 17·1 | 2·5 | 26·0 |
| Organic matter | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 9·3 | 31·3 | ... | ... | 19·5 | 24·0 | | | | |

* For these items, as also for Beam's White and Blue Nile results for 1904-5, only a few analyses have been made, and hence the results are simply the minima and maxima obtained and not the minima and maxima for the year.
† This sample contained Blue Nile water.

per second. The silt content is much less on the deflux than on the afflux.

Another important law regarding matter in suspension is that the capacity of a current to transport is limited, but every current tries to carry sediment up to its limit. If unsaturated with solid matter, a stream erodes till the saturation point is approached, and conversely, if the turbulence drops from any cause, the carrying capacity falls also, and if the stream is nearly saturated, deposit takes place.

A consequence of all this is that when silting or scour of the bed begins to take place, there is a tendency for it to continue. Scour of the bed increases the mean depth and the turbulence, and hence the silt-capacity also. Scour of the sides, however, diminishes the mean depth, the turbulence, and the silt-capacity. Hence scour of the side makes on the whole for stability of the bed; scour of the bed for instability.

Another point that must be noticed is that the rate of travel of the suspended matter is not necessarily that of the water itself, and great caution must be exercised in drawing inferences as to the total volume of solid matter discharged from the silt content. It is probable that a turbulent portion of a river maintains locally in suspension more solids than a less turbulent portion, and this solid content is so tossed about by the eddies that it takes longer to pass a given length than the water. Otherwise it is difficult to account for large local increases in the silt percentage, such as those found by Mr Frank Hughes just downstream of Bulak bridge.* Erosion alone will not suffice, for that cannot proceed indefinitely. A local increase of only 200 parts per million on a flood of 8000 cubic metres per second means a cube of $1 \cdot 6 \times 86{,}400$, or 138,000 cubic metres per day. On a breadth of, say, 400 metres, such a scour would produce disastrous results within a few days.

The proportion of silt carried by the river on occasions when freshets of the Atbara and Blue Nile are passing down the Nile is very marked. Their duration may be only twenty-four hours, though generally it extends to three or four days. The effect of high floods in scouring out the silt from the river's bed, and of low floods adding to it, is given in paragraphs 26 and 27.

The red colour of the flood water is due to the large amount of iron oxide present. The bulk of the Nile water in flood drains from the Abyssinian highlands, and so its constitution does not differ much from that of Blue Nile and Atbara water. On the other hand, the White Nile water is supplied partly by the Sobat and partly by what has filtered through the region of the sudd, and it is modified by the addition

* Mr Hughes found, in 1910, an average of about 2200 grams per cubic metre at Bulak as against less than 1900 at Kafr el Zayat bridge (*Cairo Scientific Journal*, vol. v., 53, p. 29).

of a large amount of organic matter absorbed in that region. It contains also a notable percentage of iron, derived from the iron ores of the hills of the Albert Nile.

From Table 19, which gives the amount of chlorine in Nile water at Cairo, it is evident that the amount of chlorine increases from 3 or 4 grams per cubic metre in September to 20 and 24 grams per cubic metre in June and July. This chlorine comes into the Nile with the ground water returning to the river when it is low. The chlorine is therefore highest in June and July when the Nile is at its lowest and the quantity of ground water bears a high proportion to the quantity in the river.

Downstream of the Barrages at the heads of the Rosetta and Damietta branches of the Nile, the ground water flows steadily into the branches at the time of low supply. This water is retained in the channels by means of temporary earthen dams thrown up near the sea, and the water is utilised for irrigation. No exact measurements have been made of the supply, but it is calculated that 40 cubic metres per second are added to the summer supply of the Delta in this way. The analyses of this water show a large percentage of salt, for the whole supply of the two branches upstream of the two earthen dams or sudds near their mouths is infiltration water. The analyses were made by Mr A. Lucas, and are contained in the following tables. On the upstream of the sudds is infiltration water used for irrigation, and downstream of the sudds is sea water. The nearer the surface of the water the less salty. Some sea water is always impounded upstream of the sudd when the temporary earthen bank is thrown across the river.

Mr S. H. Trimen (Survey Department Laboratories) has written as follows on the bacteriology of Nile water :—

"Since October 1904, weekly bacteriological tests have been systematically carried out in the Survey Department Laboratories. These tests have been made in connection with the control of the Government sand filters at Giza (on the west bank of the river, south of the main town of Cairo). As the samples on which the tests were made, with but few exceptions, were taken from the intake channel of the waterworks, and not from mid-stream, the results obtained from them cannot be said to be strictly representative of the river. Still, although they may not be representative, all the results are comparative, and probably closely correspond to the results that would have been obtained had the samples been taken directly from the river.

The methods used are slight modifications of those recommended by the Committee of the Royal Institute of Public Health, 1904.

It will be seen that the maximum number of bacteria occurs in the latter part of the summer while the flood is rising and before it has reached its full height. The storm-water comes from Abyssinia and causes the annual rise of the Nile. This flood in its progress rises up the banks of the river and washes out any decomposing organic matter, with the attendant microbes, which may have

TABLE 24.—ANALYSIS OF WATER AT THE MOUTHS OF THE ROSETTA AND DAMIETTA BRANCHES OF THE RIVER WHEN THEY ARE DAMMED TEMPORARILY IN SUMMER.

(Grams per cubic metre—parts per million.)

| Date. | From. | Total Soluble Salts. | Chlorine as Sodium Chloride. |
|---|---|---|---|
| May 27, 1901 . | U.S. sudd, 5 metres deep | 2082·0 | 1529·9 |
| " . | Surface Nile water, U.S. Enania | 1796·0 | 1309·6 |
| " . | Nile water, 5 metres deep, Enania Head | 2544·0 | 1923·9 |
| " . | Surface Nile water, U.S. Fara-skour village | 800·0 | 498·3 |
| " . | Surface Nile water, U.S. Damietta sudd | 2094·0 | 1506·6 |
| " . | Nile water, 5 metres deep, U.S. Faraskour | 782·0 | 498·3 |
| October 3, 1901 . | Damietta surface | ... | 3223·0 |
| " . | 10 metres below surface | ... | 3574·6 |
| " . | Faraskour surface | ... | 2051·0 |
| " . | 10 metres below surface | ... | 2168·2 |
| " . | Ataneya surface | ... | 3152·7 |
| " . | 10 metres below surface | ... | 3504·3 |
| June 6, 1902 . | Faraskour River surface water | 1272·0 | 879·0 |
| " 23, " . | River U.S. sudd, surface water | 1148·0 | 785·2 |
| " 16, 1905 . | River, Rosetta branch when ponded up | 290·0 | 61·8 |
| " 29, " . | Downstream of sudd, Rosetta branch of River | 41470·0 | 31185·0 |
| " 29, " . | Upstream of sudd, Rosetta branch of River | 450·0 | 175·0 |
| " 26, 1907 . | Upstream of sudd, Rosetta branch, Mehallet el Amir | 2908·0 | 1938·0 " |

accumulated there during the low Nile. It is to this cause that the sudden rise in the bacterial content of the river is probably due.

The minimum period occurs in the early spring—February or March—after the influence of the flood has ceased to be felt.

Generally speaking, during low Nile the number of bacteria is also low. Now it is generally assumed by people living in Egypt that Nile water is absolutely at its worst during low Nile, but that as soon as the flood arrives the water immediately

Table 25.—Average Number of Microbes per cubic centimetre.
(Agar at 37° C. for 48 hours.)

| Month. | 1904. | 1905. | 1906. | 1907. |
|---|---|---|---|---|
| January | ... | 1,668 | 3,164 | 2,925 |
| February | ... | 754 | 2,060 | 2,025 |
| March | ... | 2,168 | 1,060 | 2,226 |
| April | ... | 4,500 | 2,564 | 2,825 |
| May | ... | 2,207 | 3,723 | 3,015 |
| June | ... | 8,018 | 3,375 | 2,958 |
| July | ... | 20,696 | 5,949 | 13,250 |
| August | ... | 9,057 | 6,500 | 3,740 |
| September | ... | 8,107 | 11,695 | 4,750 |
| October | ... | 6,120 | 8,279 | 3,650 |
| November | ... | 3,400 | 3,137 | 3,225 |
| December | 2058 | 3,985 | 3,425 | 1,632 |
| Maximum | ... | 28,260 | 14,100 | 23,850 |
| Minimum | ... | 560 | 920 | 830 |

becomes sound and healthy. However this may be, during the months of April, May, and June, *i.e.* when the river is at its lowest, the number of bacteria present compares not unfavourably (with the exception perhaps of June 1905) with the number found in the winter months. The above view is doubtless due to the algæ which make their appearance about this time. They cause the green water and produce an unpleasant stagnant smell, which, though objectionable, is not necessarily harmful."

10. **Ground Water and Water in Drains.**—We quote from Mr A. Lucas's *The Chemistry of the Nile*:—

"The underground water of the Nile Valley has its origin in the river, with which it is in direct contact. When the river is in flood there is a lateral flow of the river water into the soil whereby the level of the subsoil water is raised,* and, as the river falls, a portion of this water finds its way back again into the river, and the level of the subsoil water correspondingly falls.

On the low-lying land near the river, the rise of level of the subsoil water is a visible fact, and the ground becomes covered with water. These fluctuations of the level of the water-table are well known, and their extent can best be measured

* See paragraph 12.

by the rise and fall of the water-level in wells, since the surface of the water in any well represents the level of the water table at that place.*

In 1867–8, daily records were kept of the varying levels of the water in a well at Cairo situated 1¼ miles from the river, and the results were published by Sir Benjamin Baker, *Proc. Inst. C.E.*, vol. lx.

In 1894, the Director-General of the Sanitary Department published a diagram showing the fluctuations in the water-level of three different wells at Cairo during 1890–1–2 (*The Sanitary Aspect of the Nile Reservoir*, 1899).

In 1897, Mr Karl Abel published a diagram showing the variations of level of the water in a well at Tanta, quoted by Dr Bitter, 1897.

In 1906, Captain Lyons published diagrams showing the height of the water-table at Naga Hammadi in Upper Egypt from June to October 1905, and the comparative water-levels of four wells at this place and of the Nile (*The Physiography of the Nile*, Cairo, 1906).

Since 1894, observations of the water-level in six special wells have been made weekly by the Cairo Tanzim Department, and these results have been recently summarised by the writer. From a critical study of the thirteen years' records from 1894 to 1906 inclusive, the following facts are evident:—

(1) The water-level in the wells rises and falls regularly with the rise and fall of the Nile, always, however, lagging somewhat behind the river.

(2) The nearer the well is to the river the sooner does the water-level begin to rise when the flood comes, and the greater the extent of this rise.

(3) The amount of fluctuation in the water-level varies also with the state of the flood, being highest in years of greatest flood and lowest when the flood is poor.

The greatest variations in level were recorded in 1894, and were as follows:—

| | | | | |
|---|---|---|---|---|
| 3·65 | metres at | 840 | metres from | the river.† |
| 2·53 | ” | 1440 | ” | ” |
| 2·40 | ” | 2000 | ” | ” |
| 1·49 | ” | 3440 | ” | ” |

In years of poor flood, the variations are very much less.

In 1907, nine shallow tube-wells were put down about 200 metres upstream of the Embaba bridge (in fairly sandy soil), all in a straight line at right angles to the river, and ranging from 14·5 to 38·5 metres apart, No. 1 being half a metre from the water's edge at the commencement, and No. 9, 215·5 metres away. The first permanent rise in the river recorded by the the Roda gauge, Cairo, was on June 30, and each of the nine wells showed a definite rise of water-level on the same day. On September 28, the river-level had reached its maximum and showed a total rise of 8·7 metres, while the water in No. 9 well had risen 2·4 metres.

Thus at Embaba, and doubtless elsewhere, an immense volume of additional water was manifestly present in the subsoil soon after the flood came: this additional water was seen on the low-lying ground; it submerged three of the well tubes and was measured by the increase in height of the water-level in the wells,

* Subject to provisos as to the strata pierced.

† These variations and distances are connected approximately by the equation log (range) + distance × 0·000137 = 0·644, which shows that the waves decrease in geometrical progression as the distances increase in arithmetical progression.

and it began to manifest itself the same day that the river rose. No fluid pressure, hydrostatic connection with a flooded region further south, or underground river will account for these facts. The only explanation possible is that the additional water came laterally from the Nile in the immediate vicinity of the wells.

Not only may the entry of the river water into the soil at flood-time and the return of the subsoil water to the river at ebb be shown from the rise and fall of the water-table as observed in various wells, but the actual influx and deflux may be proved in other ways. Thus, at Embaba on August 14, 1907, when the river was still rising, a small quantity of fluorescein was put into the well nearest to the river which was then above water, and within twenty-four hours the fluorescein had been transported to the well furthest inland, a distance of 150 metres, for the water in it was very distinctly coloured with the dye.

The water, which at high Nile penetrates into the soil and which slowly percolates back as the river falls, may be actually seen entering the river at several places.

'Lombardini was no untrue prophet when he wrote that he was convinced that the more carefully the discharges were taken and the results known, the more would engineers be astonished at the extraordinary amount of the subsoil water which filtered into the Nile from the head of the White Nile to the sea, and which gave back to the Nile in the months of deflux of the river the water which had percolated into the soil during the afflux. He predicted that, heavy as the evaporation was in April, May and June, in the Nile Valley, the influx of subsoil water would be found to counterbalance it' (*The Nile in* 1904). The following table shows the composition of some samples of seepage water examined in the Survey Department Laboratories:—

TABLE 26.—SEEPAGE WATERS.
(Grams per cubic metre—parts per million.)

| Sample taken from | Total Soluble Matter. | Chlorine. | Sulphuric Anhydride. | Lime. | Magnesia. |
|---|---|---|---|---|---|
| Bank at Halfa Village, east bank . | 178·0 | 17·4 | ... | 56·0 | |
| „ about three miles north of Argin Village, west bank . | 596·0 | 142·3 | 113·2 | 120·0 | 42·0 |
| „ opposite Debeira, west bank | 1902·0 | 444·2 | 443·0 | 310·0 | 67·0 |
| „ opposite pump at Debeira, west bank . . . | 1480·0 | 357·4 | 353·2 | 244·0 | 44·0 |
| „ nearly opposite pump at Debeira, 'Hammam' . | 1350·0 | 308·8 | 312·0 | 254·0 | 47·0 |
| „ between Debeira and Ashkeit, east bank . . . | 248·0 | 20·8 | ... | 90·0 | |
| „ between Debeira and Ashkeit, east bank . . . | 284·0 | 20·8 | | | |
| „ between Debeira and Ashkeit, east bank . . . | 180·0 | 6·9 | | | |

It is shown by borings made at the Roda and Embaba bridges that the bed of the Nile is pervious, being quite free from mud and consisting only of sand in certain sections. That the upper layer of Nile mud is not very permeable to

water does not affect the matter at all, since many cesspits and all percolating pits are carried through this mud into the sand below in order that the water may freely drain away. Shallow wells are also sunk through the upper stratum of mud into a lower one of sand.

Since it is the flood-water of the river with a total soluble salt content of from about 130 to 150 grams per cubic metre and a chlorine content of from about 3 to 5 grams per cubic metre that enters the soil, and not the water of low Nile, which contains from 150 to 250 grams per cubic metre of total salts and from 5 to 25 grams per cubic metre of chlorine, it naturally follows that no well water in Egypt contains less soluble salts or less chlorine than the Nile at flood-time, but that some well waters contain a little more soluble salts and chlorine and some much more, the additional amount in every case having been dissolved out of the soil through which the water has percolated to reach the well, and all differences in the composition of the various well waters are due to the variations in the nature of the soil and not to a different origin of water.

From the following table, the seasonal variation of salt in Nile water, as indicated by the quantity of chlorine present, is very evident:—

TABLE 27.—CHLORINE IN NILE WATER.
(Grams per cubic metre—parts per million.)

| Month. | Blue Nile. | White Nile. | Nile at Cairo. |
|---|---|---|---|
| January | 1·7 | 5·2 | 6·6 |
| February | 1·9 | 7·4 | 9·2 |
| March | 2·3 | 9·3 | 13·3 |
| April | 3·1 | 12·4 | 17·9 |
| May | 3·5 | 12·2 | 19·5 |
| June | 4·9 | 11·9 | 20·0 |
| July | 1·9 | 9·5 | 18·6 |
| August | 1·9 | 4·3 | 11·4 |
| September | 1·7 | 7·9 | 3·7 |
| October | 2·0 | 5·0 | 3·6 |
| November | 1·7 | 4·3 | 4·8 |
| December | 1·8 | 4·2 | 5·8 |

The salt in the water is highest everywhere when return seepage is most active, *i.e.* just before the flood, when to the salt already in the upper river is added that dissolved from the strata and washed from the land which the Nile is then draining. It is least at high flood, but even then a certain amount is dissolved from the banks.

A summary of the results of the chemical analyses of the water from the Cairo wells for 1907 is given in the following table, as also the analyses of the water from various other wells in the Nile Valley and in the Delta. From the differences shown in the composition of the water of the various wells, it is evident that the underground water varies considerably from place to place. Thus the water at Cairo does not correspond in chemical composition with the Tanta water, and even at Tanta the water in each of the four wells differs markedly in composition, the total soluble salts in the several wells varying from 262 to 530 grams per cubic metre, and the chlorine from 28·40 to 113·60 grams per cubic metre.

TABLE 28.—CAIRO WELLS.*

(In Tables 28, 29, and 30: Grams per cubic metre—parts per million.)

| Date. | Total Soluble Matter. | Chlorine. | Free Ammonia. | Albuminoid Ammonia. | Nitrites | Nitric Acid as Nitrogen. | Oxygen absorbed.† |
|---|---|---|---|---|---|---|---|
| 1907. | | | | | | | |
| January . . . | 285 | 9·6 | 0·236 | 0·039 | trace | trace | 0·82 |
| March . . . | 270 | 10·2 | 0·272 | 0·070 | trace | trace | 0·70 |
| May . . . | 273 | 11·9 | 0·321 | 0·064 | trace | trace | 0·85 |
| June . . . | 266 | 12·3 | 0·292 | 0·066 | trace | 0·02 | 0·86 |
| August . . . | 263 | 12·3 | 0·265 | 0·055 | trace | 0·03 | 0·94 |
| October . . . | 259 | 10·9 | 0·252 | 0·047 | trace | 0·01 | 0·94 |
| December . . | 247 | 10·6 | 0·348 | 0·096 | trace | 0·01 | 0·95 |
| Mean for 12 months | 267 | 11·1 | 0·286 | 0·071 | trace | 0·01 | 0·88 |

TABLE 29.—WATER COMPANY'S WELL AT ZEITUN.

| Date. | Total Soluble Matter. | Chlorine. | Free Ammonia. | Albuminoid Ammonia. | Nitrites. | Nitrates as Nitrogen. | Oxygen absorbed.† |
|---|---|---|---|---|---|---|---|
| 1907. | | | | | | | |
| January . . . | 400 | 28·7 | 0·010 | 0·020 | trace | 0·34 | 0·22 |
| March . . . | 380 | 28·2 | 0·006 | 0·030 | trace | 0·50 | 0·33 |
| May . . . | 384 | 30·1 | 0·005 | 0·025 | trace | 0·65 | 0·40 |
| June . . . | 384 | 31·1 | 0·005 | 0·010 | trace | 1·00 | 0·20 |
| August . . . | 392 | 31·9 | 0·005 | 0·005 | trace | 0·82 | 0·40 |
| October . . . | 390 | 32·2 | 0·005 | 0·013 | trace | 0·72 | 0·40 |
| December . . | 400 | 31·7 | 0·005 | 0·035 | trace | 0·62 | 0·15 |

TABLE 30.—CAIRO WATER COMPANY'S WELL AT ASSIUT.

| Date. | Total Soluble Matter. | Chlorine. | Free Ammonia. | Albuminoid Ammonia. | Nitrites. | Nitrates as Nitrogen. | Oxygen absorbed.† |
|---|---|---|---|---|---|---|---|
| 1906. | | | | | | | |
| March 26 . . | 415 | 29·0 | 1·440 | 0·170 | trace | nil | 0·65 |
| May 21 . . | 406 | 31·5 | 1·147 | 0·115 | trace | trace | 0·60 |
| June 17 . . | 410 | 33·0 | 1·180 | 0·080 | trace | trace | 1·62 |
| August 5 . . | 398 | 35·5 | 0·918 | 0·110 | much | nil | 1·02 |
| October 22 . . | 374 | 30·0 | 0·695 | 0·105 | trace | nil | nil |
| 1907. | | | | | | | |
| April 7 . . | 388 | 29·7 | 1·150 | 0·065 | trace | nil | 0·80 |
| October 19 . . | 372 | 33·6 | 0·900 | 0·048 | trace | 0·11 | 0·90 |

* Monthly means from weekly samples.

† In acid solution after boiling for ten minutes.

TABLE 31.—DEEPER TUBE WELLS.

(Grams per cubic metre—parts per million.)

| Date. | Position. | Depth. Metres. | Total Soluble Matter. | Chlorine. | Free Ammonia. | Albuminoid Ammonia. | Nitrites. | Nitrates as Nitrogen. | Oxygen absorbed.* |
|---|---|---|---|---|---|---|---|---|---|
| Aug. 2, 1903 | Zeitun . . . | 41·5 | 320 | 35·1 | ... | ... | trace | trace | |
| May 18, 1904 | Gezira } same well | 20 | 560 | 35·1 | trace | ... | trace | nil | |
| Sept. 11, 1905 | ,, } same well | 40 | 495 | 40·0 | 0·020 | 0·260 | trace | nil | |
| Mar. 2, 1907 | ,, Agr. Society . | 33 | 577 | 33·3 | 0·675 | 0·070 | trace | trace | 0·60 |
| May 29, 1905 | Bulak Dakrur . . | 25 | 970 | 211·0 | 1·305 | 0·045 | trace | nil | 1·00 |
| Oct. 1, 1901 | Giza Agr. School Dairy | 60 | 2746 | 944·3 | | | | | |
| April 29, 1903 | ,, Pumping Station | 21 | 324 | 35·0 | | | | | |
| Sept. 24, 1903 | ,, ,, | 40 | 992 | 70·0 | much | ... | nil | nil | |
| April 11, 1903 | Helwan Bore No. I. . | 22 | 232 | 28·0 | | | | | |
| ,, 27, 1903 | ,, ,, II. . | 20·7 | 1128 | 112·1 | | | | | |
| Oct. 10, 1907 | Beni Suef No. I. . | 35 | 1002 | 130·6 | 0·620 | 0·075 | trace | nil | 1·90 |
| Nov. 11, 1906 | Minia No. I. . . | 30 | 378 | 19·6 | 0·840 | 0·125 | nil | nil | 1·17 |
| Aug. 17, 1907 | Manfalut . . . | 40 | 398 | 20·0 | 0·495 | 0·053 | trace | trace | 0·72 |
| May 21, 1906 | Assiut (Prison well) . | 30 | 250 | 18·5 | 0·100 | ... | trace | trace | |
| ,, 18, 1907 | Tahta . . . | 43 | 373 | 16·7 | 0·485 | 0·030 | trace | trace | 0·70 |
| June 17, 1907 | Sohag No. I. . . | 43 | 974 | 163·6 | 0·555 | 0·055 | nil | nil | 1·70 |
| Mar. 16, 1907 | Kena . . . | 30·5 | 280 | 22·3 | 0·099 | 0·065 | nil | nil | 0·70 |
| Sept. 30, 1906 | Dessuk . . . | 46 | 2486 | 950·9 | 1·970 | 0·110 | much | nil | 3·87 |
| Aug. 26, 1907 | Kafr el Sheikh . . | 30 | 492 | 30·5 | 0·475 | 0·060 | trace | trace | 1·75 |
| Mar. 10, 1906 | Mehalla Kebir No. I. | 50 | 730 | 190·0 | 0·280 | 0·060 | nil | nil | 1·00 |
| Dec. 14, 1903 | Zagazig (Prison well) . | 35 | 676 | 191·1 | trace | ... | trace | nil | |
| Oct. 30, 1905 | ,, Bore No. I. . | 41 | 500 | 55·0 | ... | ... | nil | nil | |
| ,, ,, | ,, ,, IV. . | 44 | 710 | 108·0 | trace | ... | nil | nil | |
| Jan. 28, 1907 | ,, ,, V. . | 42 | 666 | 80·5 | 0·120 | 0·060 | trace | nil | 0·85 |
| May 2, 1905 | Menuf . . . | 20 | 500 | ... | trace | ... | nil | ... | 1·25 |
| Dec. 17, 1905 | ,, Bore No. I. . | 49·5 | 660 | 96·0 | 1·710 | 0·100 | nil | nil | 1·00 |
| Jan. 22, 1906 | ,, ,, II. . | 46 | 345 | 22·0 | 1·650 | 0·075 | nil | nil | 0·90 |
| Mar. 6, 1905 | Benha } same well | 20 | 908 | ... | 0·700 | ... | nil | | |
| June 5, 1905 | ,, } same well | 22 | 860 | 284·0 | 0·935 | 0·400 | nil | ... | 2·75 |
| ,, 25, 1906 | ,, (Test well I.) . | 30 | 334 | 24·5 | 1·165 | 0·130 | trace | nil | 1·72 |
| Nov. 6, 1906 | ,, (School) . | 48·6 | 240 | 12·3 | 0·430 | 0·030 | nil | nil | 1·75 |
| May 17, 1906 | Khanka No. I. . . | 29·5 | 237 | 15·5 | | | | | |
| July 4, 1906 | ,, ,, II. . . | 40 | 882 | 119·0 | | | | | |
| ,, 5, 1906 | ,, . . . | 46 | 854 | 120·1 | | | | | |
| ,, 7, 1907 | ,, . . . | 51 | 290 | 20·0 | 0·028 | 0·160 | trace | 0·31 | 1·55 |

* In acid solution after boiling for ten minutes.

TABLE 32.—SHALLOW OPEN WELLS.
(Grams per cubic metre—parts per million.)

| Date. | | Place. | Depth to Water-level. | Total Soluble. Matter. | Chlorine. | Free Ammonia. | Albuminoid Ammonia. | Nitrites. | Nitrates as Nitrogen. | Oxygen absorbed.* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | metres | | | | | | | |
| Nov. | 1898 | Zeitun . . . | Sakia | 2,420 | 330·0 | 0·016 | 0·140 | ... | much | |
| April | 1902 | Pont de Kubba . | ... | 584 | 63·6 | 0·015 | 0·290 | | | |
| ,, | 1903 | Marg . . . | Sakia | 1,688 | 333·9 | | | | | |
| May | ,, | Sidi Daha . . | ,, | 5,370 | 2191·7 | ... | ... | trace | little | |
| ,, | ,, | Damanhur . . | ,, | 13,963 | 5688·1 | ... | ... | much | ,, | |
| Jan. | ,, | Zeitun . . . | ,, | 1,620 | 405·1 | 0·005 | 0·165 | ,, | much | 0·92 |
| April | ,, | Sakkara . . . | ,, | 580 | 59·0 | ... | ... | ,, | 1·2 | 1·60 |
| May | ,, | Embaba . . . | 7½ | 490 | 24·0 | 0·480 | 0·130 | ,, | 0·2 | 1·30 |
| ,, | ,, | ,, . . . | 5½ | 620 | 52·0 | | | | | |
| Dec. | ,, | Near Pyramids, Giza . | ... | 385 | 48·5 | 0·125 | 0·610 | little | much | 2·50 |
| Jan. | 1906 | ,, ,, ,, | 6 | 235 | 12·5 | 0·010 | 0·070 | nil | 0·60 | 0·45 |
| Mar. | ,, | ,, ,, ,, | Sakia | 440 | 33·0 | 0·060 | 0·180 | trace | 0·20 | |
| April | ,, | ,, ,, ,, | 10 | 265 | 18·5 | 0·010 | 0·065 | ,, | 0·90 | 0·55 |
| Feb. | ,, | Assiut . . . | Sakia | 920 | 66·0 | ... | ... | ,, | nil | |
| Mar. | ,, | ,, . . . | ,, | 405 | 15·0 | ... | ... | much | 0·15 | |
| ,, | ,, | ,, . . . | ,, | 250 | 14·0 | ... | ... | little | little | |
| ,, | ,, | ,, . . . | ,, | 365 | 26·0 | ... | ... | trace | much | |
| ,, | ,, | Khanka . . . | ,, | 1,220 | 199·0 | | | | | |
| May | ,, | ,, . . . | ,, | 400 | 31·0 | ... | ... | trace | little | |

TABLE 33.—SHALLOW TUBE WELLS.
(Grams per cubic metre—parts per million.)

| Date. | | Place. | Depth in Metres. | Total Soluble Matter. | Chlorine. | Free Ammonia. | Albuminoid Ammonia. | Nitrites. | Nitrates as Nitrogen. | Oxygen absorbed.* |
|---|---|---|---|---|---|---|---|---|---|---|
| May | 1903 | Damanhur . . | 18 | 1426 | 490·5 | ... | ... | much | nil | |
| Oct. | 1905 | ,, . . | ... | 320 | 23·5 | 0·545 | 0·210 | little | trace | 1·20 |
| June | 1903 | Mataria . . . | ... | 584 | 56·0 | 0·085 | 0·210 | nil | 6·9 | 1·30 |
| Oct. | 1904 | Roda Island (same well) | 15 | 288 | 27·7 | 0·010 | 0·080 | ,, | nil | |
| May | 1905 | ,, (same well) | ,, | 580 | 70·0 | nil | 0·050 | trace | ,, | 0·45 |
| Oct. | ,, | ,, (same well) | ,, | 450 | 67·0 | ,, | 0·075 | nil | ,, | 0·65 |
| Jan. | ,, | Benha . . . | ... | 1300 | 356·0 | much | ... | ,, | ,, | 9·60 |
| Sept. | 1906 | ,, . . . | 18 | 1000 | 118·3 | 0·035 | 0·115 | much | much | 2·00 |
| Mar. | 1905 | Tahta . . . | ... | 680 | 44·0 | 0·040 | 0·080 | trace | 3·4 | 0·65 |
| June | ,, | Shubra . . . | 10 | 340 | 10·5 | 0·310 | 0·170 | nil | ,, | 1·90 |
| ,, | ,, | Zagazig . . . | 13 | 580 | 20·0 | 0·425 | 0·565 | ,, | trace | 4·65 |
| May | 1906 | Tanta . . . | ... | 2868 | 940·0 | 0·505 | 0·155 | trace | nil | 2·02" |

* In acid solution after boiling for ten minutes.

Drains as ordinarily understood carry away either water which has been used for washing lands and ground water, but what are called drains in Egypt are in very many cases only escapes carrying off the excess water of the canals.

We quote from a paper by Mr A. Lucas on the "Salt Content of some Agricultural Drainage Waters in Egypt" (p. 413 of the *Cairo Scientific Journal*, 1908):—

"The whole of the agricultural drainage water from the cultivated lands of Lower Egypt is discharged either into the various existing salt lakes or directly into the sea, and none of it enters the Nile: thus the Fayum drainage goes to Lake Karun, that of the Wadi Tumilat to Lake Timsah, and the remainder either to the various lakes along the coast, such as Mariut, Edku, Borollos, and Menzala, or to the sea.

In Upper Egypt, however, agricultural drains enter the Nile at Beni Suef, Feshn, and Etsa.

The injurious materials likely to be present in the soil are common salt (sodium chloride), sodium sulphate, and sodium carbonate, and as all these compounds are soluble in water they will be washed out to some extent during irrigation, and so will find their way into the drains. An analysis therefore of the drainage water affords an indication of the comparative amount of injurious salts in the soil.

The composition of the drainage water is also useful as showing whether it is safe to use such water for irrigation purposes at any time when water is scarce. With regard to this point, however, no hard and fast line can be drawn between a water that is fit for irrigation purposes, and one that is unfit, since the amount of harmful salts that may be present before the crops are injuriously affected varies with the extent to which the salts themselves occur in the soil, with the amount of evaporation and concentration that takes place after the application of the water, and especially with the conditions of drainage. Water containing a comparatively large amount of injurious salts may be applied with perfect safety to land that is well drained, whereas the effect of the same water on badly drained land would be disastrous. It was found in America that in one locality 5000 parts of soluble matter per million parts of water might be taken as the extreme limit of endurance for plants, while 2500 to 3000 parts per million marked the danger point at which the results of the use of the water were uncertain. In another locality 3000 parts of soluble matter per million was the extreme of safety.*

It should be noted, however, that of the total soluble matter contained in a water only about 50 per cent. is likely to be harmful.

The total soluble matter in Nile water during the three years 1905–6–7 varied from 120 parts per million to 260 parts per million.

The water from the Upper Egypt drains contains only about half as much again of soluble matter as Nile water and might be used for irrigation purposes at any time with perfect safety.

In Lower Egypt, however, the composition of the drainage waters is very different, the minimum amount of soluble matter being from twice to eight times

* *U.S. Department of Agriculture Report*, No. 64, Washington, 1900.

and the maximum from three to one hundred and eighteen times that of the minimum and maximum respectively of the Upper Egypt drains, and although only occasional samples were taken, and those for the most part in the summer before the plentiful supply of flood water had reached the land, and when water was scarce and evaporation high, and when therefore the condition of the drainage water was at its worst, yet the enormous difference in composition between the samples from Upper and Lower Egypt can only be due to the fact that the land in Lower Egypt contains a far larger proportion of soluble salts than that of Upper Egypt.

In no case do the samples include water from the lakes into which the drains ultimately discharge.

TABLE 34.—NILE WATER.*

(Grams per cubic metre—parts per million.)

| | 1905. | | 1906. | | 1907. | |
|---|---|---|---|---|---|---|
| | Total Soluble Matter. | Chlorine. | Total Soluble Matter. | Chlorine. | Total Soluble Matter. | Chlorine. |
| Minimum . | 125·0 | 2·5 | 124·0 | 3·2 | 120·0 | 3·3 |
| Maximum . | 260·0 | 26·0 | 239·0 | 24·5 | 238·0 | 20·6 |

* Samples taken weekly at Giza.

TABLE 35.—DRAINAGE WATER FROM UPPER EGYPT.*

(Grams per cubic metre—parts per million.)

| | 1907. | | 1908. | |
|---|---|---|---|---|
| | Total Soluble Matter. | Chlorine. | Total Soluble Matter. | Chlorine. |
| Minimum . . | 172·0 | 7·6 | 168·0 | 3·0 |
| Maximum . . | 352·0 | 47·9 | 400·0 | 34·0 |

* Samples taken about twice a month.

TABLE 36.—DRAINAGE WATER FROM LOWER EGYPT.

(Grams per cubic metre—parts per million.)

| Year. | Drainage System finally discharging | | Total Soluble Matter. | Chlorine. | Sulphuric Anhydride. |
|---|---|---|---|---|---|
| 1905 | Into Lake Mareotis * . . | Minimum<br>Maximum | 1,338·0<br>6,386·0 | 427·0<br>2,078·0 | 181·4<br>588·5 |
| 1905 | Into Lake Edku * . . | Minimum<br>Maximum | 446·0<br>1,106·0 | 99·9<br>410·9 | 34·6<br>93·6 |
| 1905 | Into Lake Borollos † . . | Minimum<br>Maximum ‡ | 600·0<br>44,224·0 | 186·5<br>21,343·0 | 39·7<br>2,595·7 |
| 1905 | Into sea, east of Borollos § . | Minimum<br>Maximum | 396·0<br>3,034·0 | 124·3<br>1,243·3 | 17·5<br>141·6 |
| 1905 | Into Lake Menzala ‖ . . | Minimum<br>Maximum | ...<br>... | 399·9<br>2,999·2 | |
| 1902 | Into Lake Timsah ¶ . . | Minimum<br>Maximum | 800·0<br>1,256·0 | 180·8<br>362·2 | 121·5<br>229·7 |
| 1903 | ,, ,, ¶ . . | Minimum<br>Maximum | 812·0<br>1,524·0 | 175·7<br>400·0 | 91·9<br>217·4 |
| 1901 | Into Lake Karun ** . . | Minimum<br>Maximum | 1,012·2<br>3,498·0 | 330·1<br>1,264·3 | 141·9<br>633·7 |
| 1907 | ,, ,, †† . . | Minimum<br>Maximum | 568·0<br>2,920·0 | 163·2<br>999·1 | |

* Occasional samples, July to October.
† Occasional samples, July to August.
‡ Sharkawia No. 4 drain in August; practically the same composition as the sea.
§ Occasional samples, August.
‖ Occasional samples, June.
¶ Monthly samples.
** Occasional samples, January to April.
†† Occasional samples, May to December.

TABLE 37.—MEDITERRANEAN SEA AT ALEXANDRIA.*
(Grams per cubic metre—parts per million.)

| | Total Soluble Matter. | Chlorine. | Sulphuric Anhydride. |
|---|---|---|---|
| Minimum | 43,584·0 | 21,375·2 | 2,551·5 |
| Maximum | 44,440·0 | 21,861·0 | |

* A few samples taken in May 1907 on the coast between Mex and San Stefano.

The following is from the *Irrigation Report for* 1904, where Mr Langley gives the results of salt tests of drainage water in the Lower Egypt drains made with the "Electric Bridge Machine" (Western Electric Company, New York):—

TABLE 38.—DRAINAGE WATER IN LOWER EGYPT.

| Date of Test. | Site from which Sample was taken. | Number of parts Salt per million. |
|---|---|---|
| 1904. September 28 | Bahr Saft Drain, Abu Shekuk | 270 |
| ,, 29 | ,, ,, tail of Bahr Attil | 430 |
| ,, 29 | ,, ,, 5 kilometres from tail | 600 |
| ,, 29 | ,, ,, at tail | 1000 |
| ,, 30 | Bahr Fakus at San | 660 |
| October 1 | Bahr Tawil, kilometre 3·500 | 820 |
| ,, 1 | Tail of Bahr Hadus | 940 |
| ,, 1 | Tail of Masraf Umum el Behera | 650 |
| ,, 2 | Bahr Hadus at Dawar Salama | 550 |
| ,, 2 | Tail of Gabbada drain | 380 |
| ,, 2 | Tail of Nizam drain | 480 |
| ,, 2 | Tail of Buhia drain | 370 |
| ,, 2 | Hemari drain, 6 kilometres from tail | 480 |

The flood discharge of the canals was at its maximum when the observations were made, which accounts for the low percentages of salt obtained. What follows is from the report for 1905.

In last year's report was given a table showing the results of some tests of drainage water for salt made in the first circle during flood. The following table gives the results of a series of tests made all over the Delta during summer, and compares them with those observed during flood at the same sites:—

TABLE 39.—DRAINAGE WATER IN LOWER EGYPT.

| Circle. | Drain and Site from which Samples were Taken. | Parts per million of Salts. | |
|---|---|---|---|
| | | July. | October. |
| 1st | Bahr Saft drain at Abu Shekuk | 1320 | 270 |
| „ | „ „ „ at tail of Bahr Attil | 1980 | 430 |
| „ | „ „ „ 5 kilometres from tail | 1980 | 600 |
| „ | „ „ „ tail | 2640 | 1000 |
| „ | Bahr Fakus drain at San | 2310 | 660 |
| „ | Bahr Tawil drain at kilometre 3·500 | 1650 | 820 |
| „ | Bahr Hadus drain at tail | 1650 | 940 |
| „ | Masraf Umum el Behera | 1650 | 650 |
| „ | Bahr Hadus drain at Dawar Salama | 1150 | 550 |
| „ | Gabbada drain at tail | 1150 | 380 |
| „ | Nizam drain at tail | 660 | 480 |
| „ | Buhia drain at tail | 1320 | 370 |
| „ | Hemari drain at 6 kilometres from tail | 990 | 480 |
| 2nd | No. VII. drain at Wasat regulator | 510 | |
| „ | „ „ „ at Bahr Adma syphon | 1140 | |
| „ | No. VIII. drain at Kafr Sheikh-Rowena road | 700 | |
| „ | „ „ „ opposite Sidi Salem | 2430 | |
| „ | No. IX. drain opposite Lasefar Village | 780 | |
| „ | „ „ „ at tail | 2010 | |
| „ | No. XI. drain at Koddaba Canal syphon | 1250 | |
| „ | Junctions drains No. X. and XI. | 1670 | |
| Zifta | Mohit drain (No. 1) at kilo 39 opposite Demera | 280 | |
| „ | „ „ „ at junction of Abu Nom drain | 1540 | |
| „ | Demelash drain (No. 2) at kilometre 30 | 610 | |
| „ | „ „ „ at kilometre 4 | 2320 | |
| „ | Sharkawia drain No. IV. at railway | 1120 | |
| „ | „ „ „ at kilometre 10 | 3990 | |
| „ | Ibshan drain No. V. at Barari railway | 1200 | |
| „ | „ „ „ at Halafi Lock | 2620 | |
| „ | Samatai drain No. VI. at kilometre 28, Banawan | 440 | |
| „ | „ „ „ at kilometre 7 below syphon | 1650 | |
| 3rd | Deshuri drain at junction with Masraf Umum | 3160 | 1550 |
| „ | Nubaria drain at junction with Masraf Umum | 3520 | 3430 |
| „ | Shereshra drain at junction with Masraf Umum | 2870 | 820 |
| „ | Gabbares drain at junction with Shereshra | 1500 | |
| „ | Defisha drain at Beda | 1720 | 700 |
| „ | Edku drain 5 kilometres north of Fransawia Canal | 870 | 350 |
| „ | „ „ at junction with Shibrakhit drain | 320 | 220 |
| „ | Khairi drain at Mahmudia syphon | 470 | 190 |
| „ | „ „ at junction of Khandak Gharbi drain | 260 | 170 |
| „ | Tel el Barud drain, midway | 390 | 220 |
| „ | Shibrakhit drain, midway | 300 | 440 |
| „ | Junction of Umum and Damanhur drains | ... | 1050 |
| „ | Edku drain at Zarkan syphon | ... | 610 |

The last selection is from the *Irrigation Report for* 1909:—

"Mr Ireland, the Inspector-General of Basin Conversion Works, has furnished a very interesting statement giving the saltness in the new main drain of the West Giza Conversion Works in Upper Egypt. The specimens were obtained twice a month near the Abu el Numros syphon, and analysed by Mr Lucas at the laboratory of the Survey Department. It will be seen from these results that the maximum saltness recorded in parts per million was 860, the average being only 420, while that observed at the end of August and the early part of September was as low as 200.

The drain water, therefore, was for the whole year fresh enough for irrigation, and for most of the season was even suitable enough for drinking purposes.

TABLE 40.—RESULT OF ANALYSIS OF DRAINAGE WATER CARRIED OUT BY THE SURVEY DEPARTMENT LABORATORY IN 1909, OBTAINED FROM ABU EL NUMROS DRAIN NEAR WARDAN.

(Grams per cubic metre—parts per million.)

| Date. | Total Soluble Matter. | Chlorine. | Sodium Chloride. |
|---|---|---|---|
| January 26 | 660·0 | 142·6 | 235·3 |
| February 15 | 860·0 | 187·5 | 309·3 |
| March 1 | 248·0 | 32·0 | 52·8 |
| March 31 | 440·0 | 78·6 | 129·6 |
| April 17 | 356·0 | 55·3 | 91·2 |
| May 15 | 412·0 | 72·9 | 120·3 |
| May 30 | 824·0 | 191·0 | 315·1 |
| June 30 | 292·0 | 29·1 | 48·0 |
| July 17 | 256·0 | 27·8 | 45·8 |
| August 16 | 256·0 | 35·9 | 59·2 |
| August 30 | 196·0 | 8·7 | 14·4 |
| September 15 | 196·0 | 13·6 | 22·4 |
| October 17 | 270·0 | 36·9 | 60·8 |
| November 15 | 330·0 | 33·0 | 54·4" |

Mr Victor Mosséri has made many hundreds of analyses of drain water. The two following tables give a fair idea of the salt contents of private and public drains, water in rice fields, and percolation water during the period of rice cultivation. Mr Mosséri writes:—

"It will be seen that chloride of sodium constitutes 50 per cent. of the total salts, while the composition varies between wide limits.

Percolation water contains from 9000 to 30,000 parts in a million in summer, and from 4500 to 15,000 in flood; the water in the rice fields from 300 to 900 in summer, and from 100 to 600 in flood. The proportion of 600 per million was reached on the 10th September, when the percolation water contained 15,000 per million. It fell to 300 per million on the 16th of the same month, and remained constant to the end of the flood.

TABLE 41.—CHLORIDE OF SODIUM (COMMON SALT) IN DRAINAGE WATER IN THE RICE LANDS OF LOWER EGYPT.

(Parts per million.)

| Source of Water. | May 20, 1910. | May 29, 1910. | July 29, 1910. | Aug. 5, 1910. | Aug. 30, 1910. | Sept. 10, 1910. | Sept. 16, 1910. | Sept. 30, 1910. | Oct. 2, 1910. | Oct. 8, 1910. | Oct. 18, 1910. | Oct. 28, 1910. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percolation water . . | 27,000 | 11,100 | 10,800 | 30,000 | 9000 | 15,000 | 8,400 | 4,500 | 10,800 | 6,400 | 6,600 | 10,500 |
| ,, ,, . . | ... | ... | ... | ... | ... | 14,400 | 10,200 | 15,000 | 13,200 | 16,500 | 12,800 | 12,300 |
| ,, ,, . . | ... | ... | ... | ... | ... | 14,400 | ... | 7,800 | ... | 3,200 | 8,300 | 8,700 |
| Surface water, rice fields . | ... | 600 | 700 | 300 | 900 | 600 | 300 | 400 | 300 | 300 | 100 | 300 |
| ,, ,, . | ... | ... | ... | ... | ... | 600 | 3,900 | ... | ... | 1,700 | 900 | 800 |
| ,, ,, . | ... | ... | ... | ... | ... | 300 | ... | 400 | ... | 100 | 400 | 200 |
| Private drain . . . | ... | 8,800 | 2,800 | 12,000 | 3300 | 500 | 2,600 | 1,500 | 700 | 3,100 | 1,600 | 300 |
| ,, . . . | ... | ... | ... | ... | ... | 4,800 | ... | 2,400 | 1,800 | 1,700 | 7,200 | 1,200 |
| Public drain . . . | ... | ... | 3,100 | 7,600 | 1500 | 2,700 | 1,500 | 3,700 | 1,300 | 1,200 | 9,300 | 1,500 |

TABLE 42.—ANALYSIS OF DRAINAGE WATER IN RICE LANDS IN LOWER EGYPT IN PARTS PER MILLION OF WATER.

| Constituents. | October 8, 1910. | | October 18, 1910. | | October 8, 1910. | | October 18, 1910. | | October 18, 1910. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Water. | Dry Residue. | Water. | Dry Residue. | Water. | Dry Residue. | Water. | Dry Residue. | Water. | Dry Residue. |
| | | Per cent. | | Per cent. | | Per cent. | | Per cent. | | Per cent. |
| Sulphate of lime . . . | 950 | 9·6 | 1,250 | 12·1 | 1,970 | 8·9 | 1,290 | 7·5 | 240 | 26·7 |
| Sulphate of magnesia . . | 1330 | 13·4 | 1,130 | 11·0 | 1,720 | 7·8 | 1,720 | 10·2 | 20 | 2·2 |
| Chloride of magnesia . . | 830 | 8·4 | 950 | 9·0 | 2,690 | 12·2 | 1,620 | 9·4 | 70 | 7·7 |
| Chloride of sodium . . | 5400 | 54·6 | 5,510 | 53·2 | 13,200 | 60·0 | 10,850 | 63·2 | 260 | 28·9 |
| Bicarbonate of sodium . . | 610 | 6·2 | 640 | 6·2 | 670 | 3·0 | 760 | 4·4 | 310 | 34·5 |
| Dry residue . . | 9880 | ... | 10,360 | ... | 22,000 | ... | 17,160 | ... | 900 | |

The percolation water is much more charged with salt than the surface water in the fields. On the 5th of August it was one hundred times more salt than the water in the fields. The salt in the percolation water is heaviest when there is little water to irrigate with and the water has consequently stood long in the fields. The contrary holds good when water is plentiful in flood."

**11. Evaporation and Absorption.**—In the second edition this subject was treated as follows :—

"The rise and fall of spring levels depend on the soil, which varies considerably. Where the ordinary compact soil of Egypt is met with, the rise of the Nile has not much effect at the surface of the country. The Nile may be 3 metres above the level of the country, and the fields will be as dry as in the height of summer. Where, however, the soil is sandy, a few days after the Nile has risen about a metre above the level of the country, every field becomes a stagnant pool of black water, which reaches up to half a kilometre from the river, and in some places even a kilometre. Immediately the Nile falls, however, the spring level falls with it. The water in the wells rises and falls with the river, much in some places, little in others. At a well near Cairo, in apparently sandy soil, Sir J. Fowler found the water rise 3·7 metres above its minimum, while the Nile rose 6·1 metres. The wells in the Delta depend for their springs as much on the main canals as on the Nile itself. The spring level in the southern half of the Delta proper has been permanently raised by the extra height to which the water has been held up in summer at the Barrages since 1884. Fellahin have frequently informed me that, owing to this rise, they have been enabled to put in extra wells, both on account of the extra water, and of the easiness of lifting it two metres or so less than before. (The rise of spring level constitutes a very great danger to Lower Egypt.) In hollows and tanks in the clay soil there is little water during the floods, as evaporation is more active than infiltration in such soil. During winter, however, the infiltrations continue, the evaporation decreases, and the tanks soon fill. In clay soil, therefore, infiltration may be taken as less than the evaporation in Lower Egypt in August and September. The percolation or infiltration is considerably in excess of the summer evaporation in the sandy tracts, while in the clay tracts it lies somewhere between the flood and winter evaporation of Lower Egypt."

From the figures in Table 44 the absorption through clay soil would lie between 3·6 and 2·2 millimetres per day under the ordinary conditions of pressure on the Nile bank.

The factors influencing evaporation from a free water surface are so numerous and variable that the greatest care must be exercised in applying facts obtained in one locality to another. The rate of evaporation depends on the saturation deficit, or amount by which the pressure of water vapour in the air falls short of that proper to the temperature for saturation; on the velocity of the wind; on the temperature of the water (and so probably on its depth); and on the extent and form of the water surface, for near the centre of a large reservoir the air becomes more saturated than near the edge, and evaporation is feebler. Experiments under artificial condi-

tions differ so much *inter se* that they can hardly be expected to give a true representation of what occurs in nature, and observations in natural conditions are, in general, complicated by the existence of unknown seepage into and from the reservoir, and by rainfall.

Mr Desmond Fitzgerald studied the evaporation from the reservoirs of Boston Waterworks and found a formula

$$E = 0{\cdot}4\,(f-e)\left(1+\frac{5v}{16}\right),$$

where $E$ is the daily evaporation in millimetres, $f$ and $e$ are the vapour pressures in millimetres corresponding to the temperature of the water and the dew-point, and $v$ is the wind velocity in kilometres per hour. The chief difficulty in the way of using this formula is to obtain the velocity of the wind. Professor Carpenter found a similar equation to Fitzgerald's, but with a different factor (viz. $\frac{1}{16}$) for the wind, owing to his measurement of wind velocity being made at a considerable height above the water surface. Carpenter's formula gives much better results with the data obtainable in Egypt, and may be employed when no other data are available.

As regards actual measurement of evaporation in Egypt, reference may be made to a paper by Mr B. F. E. Keeling,* where details are given. Most measurements of evaporation have been made in meteorological screens with instruments of the Wild or Piche pattern, but there exist comparisons between the amounts so obtained and the evaporation from water-jacketed tanks. On the Nile at Giza the following values were found :—

TABLE 43.—EVAPORATION IN MM. PER DAY.

| | 1907. | 1908. |
|---|---|---|
| January . . . | ... | 2·8 |
| February . . . | ... | 2 8 |
| March . . . | ... | 4·0 |
| April . . . | ... | 4·2 |
| May . . . | 7·0 | 6·5 |
| June . . . | 7·3 | 6·7 |
| July . . . | 6·3 | 5·6 |
| August . . . | 4·0 | |
| September . . | 3·7 | |
| October . . . | (3·0) | |
| November . . | 2·5 | |
| December . . | 3·2 | |

* *Evaporation in Egypt and the Sudan*, Cairo, 1909.

Mr Keeling's results may be summed up in the ratios

| Instrument. | Wild. | Wade. | Piche. | Wire Tank. | Nile. | Lake. |
|---|---|---|---|---|---|---|
| Relative evaporation . | 100 | 155 | 142 | 72 | 90 | 110 |

In the case of the Nile, the ratio was obtained by comparing a Wild evaporimeter at Giza meteorological station with evaporation from a tank in the river at Roda Bridge. The ratio for a "lake" depends on a double indirect comparison and may be defective; but on the whole, for reservoirs in the Nile, it appears safer to adopt this than that for the river flowing between banks. From a comparison of the measurements made by different evaporimeters in screens all over Egypt and the Sudan we have constructed the following table, which may be used, failing more precise determinations. On the whole, it gives slightly too high values in winter and slightly too low in summer when compared with evaporation measured from free water surfaces or from tanks properly jacketed, at Alexandria, in the northern lakes, on Lake Karun, at Aswan, and on the White Nile. The values obtained by M. Audebeau Bey* from barrels of 50 cm. diameter suitably insulated gave results much higher than the figures of Table 44, but the smallness of the evaporating surface employed sufficiently explains the discrepancy. M. Audebeau points out, however, that his figures may be more applicable to small water courses than those obtained by us.

TABLE 44.—EVAPORATION FROM A FREE WATER SURFACE.†

In millimetres per day.

| District. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Egypt . | 2·3 | 2·9 | 3·5 | 4·2 | 4·7 | 5·0 | 4·6 | 4·3 | 3·6 | 3·5 | 2·9 | 2·2 | 3·6 |
| Upper Egypt . | 3·9 | 4·4 | 5·7 | 8·2 | 10·3 | 12·4 | 12·2 | 11·1 | 8·8 | 7·0 | 5·2 | 3·7 | 7·7 |
| North Sudan . | 7·9 | 9·1 | 11·0 | 12·3 | 13·4 | 13·7 | 12·2 | 11·4 | 11·8 | 11·4 | 10·0 | 7·9 | 11·0 |
| Blue Nile . | 8·9 | 10·5 | 11·8 | 12·1 | 10·7 | 8·9 | 6·1 | 5·0 | 5·4 | 6·9 | 9·2 | 8·8 | 8·7 |
| White Nile . | 11·3 | 12·2 | 13·1 | 12·3 | 10·9 | 9·1 | 6·1 | 5·0 | 5·2 | 7·5 | 10·7 | 10·9 | 9·5 |
| Sudd region . | 10·8 | 11·1 | 10·5 | 7·4 | 5·6 | 4·2 | 3·1 | 2·6 | 3·1 | 4·0 | 6·9 | 9·3 | 6·6 |

* *Rapport présenté à la Commission des Domaines*, 1909, p. 28, and 1910, p. 29.

† For an explanation of the data employed in the construction, see *Cairo Scientific Journal*, vol. vi., 1912, p. 104. We are now of opinion that the values for the White Nile are too low, and we shall return to the subject in CHAPTER III., paragraph 37, and Appendix A.

Mr P. M. Tottenham, Inspector-General of the Sudan Irrigation Service, has sent us the result of the first twenty days' experiments on evaporation from a tank supported on a raft floating in the White Nile at Khartoum at the end of April 1912. The experiments were conducted by Mr R. Türstig, who writes:—

"I have observed now for nearly twenty days, during which I obtained hourly readings for the time from 6 a.m. to 6 p.m.

Pending a detailed report, I wish to communicate to you to-day only the following preliminary data. I may add I have reasons to believe that the actual losses of the river surface are not less than these figures (in millimetres):—

| | Average. | Maximum. | Minimum. |
|---|---|---|---|
| Daily total . . . . | 13·3 | 24·7 | 6·8 |
| 6 a.m. to 6 p.m., day . . | 8·8 | 16·7 | 5·0 |
| 6 p.m. to 6 a.m., night . . | 4·5 | 9·1 | 1·2 |

The range, as you see, is very large; this, as the detail will show, depends chiefly upon the wind.

The instrument itself is satisfactory, though I may suggest later on some simple improvements. The small floating tank (rain-gauge) is most useful for checking, and both agree so far as it may be expected."

*Evaporation from Plants and the Soil.*—M. Audebeau Bey has carried out a careful series of observations on the evaporation from bare soil with spring level maintained at different depths. He finds the following results:—

TABLE 45.—DEPTH OF WATER EVAPORATED PER 24 HOURS IN MILLIMETRES AT KORASHIA IN THE HEART OF THE DELTA.

| Month. | Spring level 1·50 m. | | Spring level 0·75 m | |
|---|---|---|---|---|
| | Loamy Soil. | Clay. | Loamy Soil. | Clay. |
| April . . | ... | ... | 4·3 | 2·6 |
| May . . | 0·9 | 0·9 | 4·8 | 2·9 |
| June . . | 0·8 | 0·8 | 3·9 | 2·0 |
| July . . | 0·8 | 0·8 | 3·7 | 1·9 |
| August . . | 0·4 | 0·4 | 2·6 | 1·5 |
| September . | 0·3 | 0·3 | 2·6 | 1·2 |
| October . . | 0·3 | 0·2 | 2·1 | 1·0 |

It will be noticed that evaporation from loamy soil is about equal to that from clay when the spring level is kept at a depth of 1½ metres, but the former is twice the latter when the level is raised to 75 centimetres from the surface. Halving the depth of saturation has had the

effect in the two classes of soil of increasing the amount evaporated five-fold and threefold respectively, and brings it up nearly to that from a free water surface. When the salt content of summer water is taken into consideration (see Table 18) we find that from 0·6 to 3·0 kilograms of salt per acre per day are left in the soil to be washed from it partially or wholly by the flood waterings, or removed in the drainage water.

*Absorption.*—According to Mr F. Hughes,* 100 parts of dry Nile mud require 15 parts of water to moisten it, 55 parts of water to saturate it, and 65 parts of water to waterlog it. Mr A. Lucas finds numbers nearly the same, viz. 59 per cent. of water by volume for saturation, and 65 per cent. for waterlogging. The dried Nile mud here referred to was slightly loosened from its natural packing, and in the field it is probable that 50 to 55 per cent. of water by volume is required for saturating bone-dry soil, and the smaller number will be employed by us. It must be remembered, however, that the hygroscopic condition of the soil and subsoil varies from extreme dryness at the surface in summer to saturation at variable depths. It is advisable therefore to halve the above percentage and adopt 25 per cent. as the average water content of the soil above the level of saturation, and also the average absorption in natural soil.

An important deduction may be drawn as to the amount of water stored temporarily in the subsoil. Measurements of the depth of the saturation layer from the fifteen diagrams in Mr Ferrar's book give the following table of the average of the layer.

* Quoted by Ferrar, *Subsoil Water*, p. 29.

[TABLE.

TABLE 46.—AVERAGE DEPTH OF THE GROUND WATER IN 1908.

In metres below the surface.

| | Basin Irrigation. | | | | | | | | | | | Perennial Irrigation. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Edfu. | Esna. | Karnak. | Kift. | Kena. | Dishna. | Naga Hammadi. | Girga. | Sohag. | Tahta. | Assiut. | Minia. | Beni Suef. | Wasta. | Giza. |
| January | 3·6 | 5·3 | 5·7 | 4·7 | 6·2 | 4·4 | 4·0 | 3·2 | 4·2 | 3·3 | 3·8 | 2·1 | 2·6 | 3·3 | 2·0 |
| February | 4·0 | 5·7 | 6·0 | 4·8 | 6·6 | 4·7 | 4·5 | 3·7 | 4·7 | 3·9 | 4·1 | 2·3 | 2·8 | 3·5 | 2·3 |
| March | 4·4 | 6·0 | 6·4 | 5·1 | 7·0 | 5·0 | 5·0 | 4·2 | 5·2 | 4·4 | 4·4 | 2·6 | 2·9 | 3·6 | 2·7 |
| April | 4·9 | 6·2 | 6·7 | 5·4 | 7·2 | 5·4 | 5·2 | 4·7 | 5·6 | 5·0 | 4·7 | 2·7 | 3·3 | 3·7 | 3·1 |
| May | 5·2 | 6·4 | 7·0 | 5·6 | 7·4 | 5·6 | 5·4 | 5·2 | 6·1 | 5·6 | 5·1 | 3·0 | 3·6 | 3·9 | 3·4 |
| June | 5·5 | 6·6 | 7·3 | 5·9 | 7·6 | 5·9 | 5·6 | 5·8 | 6·7 | 6·1 | 5·4 | 3·5 | 3·9 | 4·4 | 4·0 |
| July | 6·0 | 6·8 | 7·5 | 6·0 | 7·8 | 6·2 | 5·8 | 6·3 | 6·9 | 6·5 | 5·7 | 3·4 | 4·1 | 4·2 | 4·3 |
| August | 6·4 | 7·0 | 7·5 | 6·3 | 7·8 | 6·3 | 6·0 | 6·1 | 6·9 | 6·4 | 5·8 | 3·3 | 4·0 | 4·5 | 4·8 |
| September | | | | | | | | | | | | | | | |
| October | | | | | | | | | | | | | | | |
| November | 0·5 | 2·4 | 1·9 | 1·6 | 3·7 | 0·8 | 1·5 | 0·4 | 1·1 | 0·8 | 1·0 | 0·7 | 0·6 | 0·7 | 0·2 |
| December | 2·3 | 3·5 | 3·2 | 2·6 | 5·2 | 2·2 | 2·5 | 1·7 | 2·6 | 2·0 | 2·1 | 1·3 | 1·4 | 1·4 | 1·0 |

From this table may be deduced another showing the monthly fall of the ground water level from November, when it is at its highest, to July and in places August, when it is at its lowest. From August to November the ground water is rising.

TABLE 47.—MONTHLY FALL OF GROUND WATER IN 1909 IN METRES FROM NOVEMBER TO AUGUST.

| | Basin Irrigation. | | | | | | | | | | Perennial Irrigation. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Edfu. | Esna. | Karnak. | Kift. | Kena. | Dishna. | Naga Hammadi. | Girga. | Sohag. | Tahta. | Assiut. | Minia. | Beni Suef. | Wasta. | Giza. |
| December | 1.8 | 1.1 | 1.3 | 1.0 | 1.5 | 1.4 | 1.0 | 1.3 | 1.5 | 1.2 | 1.1 | .6 | .8 | .7 | .8 |
| January | 1.3 | 1.8 | 2.5 | 2.1 | 1.0 | 2.2 | 1.5 | 1.5 | 1.6 | 1.3 | 1.7 | .8 | 1.2 | 1.9 | 1.0 |
| February | .4 | .4 | .3 | .1 | .4 | .3 | .5 | .5 | .5 | .6 | .3 | .2 | .2 | .2 | .3 |
| March | .4 | .3 | .4 | .3 | .4 | .3 | .5 | .5 | .5 | .5 | .3 | .3 | .1 | .1 | .4 |
| April | .5 | .2 | .3 | .3 | .2 | .4 | .2 | .5 | .4 | .6 | .3 | .1 | .4 | .1 | .4 |
| May | .3 | .2 | .3 | .2 | .2 | .2 | .2 | .5 | .5 | .6 | .4 | .3 | .3 | .2 | .3 |
| June | .3 | .2 | .3 | .3 | .2 | .3 | .2 | .6 | .6 | .5 | .3 | .5 | .3 | .5 | .6 |
| July | .5 | .2 | .2 | .1 | .2 | .3 | .2 | .5 | .2 | .4 | .3 | + .1* | .2 | + .2* | .3 |
| August | .4 | .2 | ... | .3 | .. | .1 | .2 | + .2* | ... | + .1* | .1 | + .1* | + .1* | .3 | .5 |
| November–January | 3.1 | 2.9 | 3.8 | 3.1 | 2.5 | 3.6 | 2.5 | 2.8 | 3.1 | 2.5 | 2.8 | 1.4 | 2.0 | 2.6 | 1.8 |
| January–August | 2.8 | 1.7 | 1.8 | 1.4 | 1.6 | 1.9 | 2.0 | 2.7 | 2.7 | 3.1 | 2.0 | 1.2 | 1.4 | 1.2 | 2.8 |
| August–November | 5.9 | 4.6 | 5.6 | 4.7 | 4.1 | 5.5 | 4.5 | 5.7 | 5.8 | 5.6 | 4.8 | 2.6 | 3.4 | 3.8 | 4.6 |

* Ground water rising.

We make these preliminary remarks about these tables. In the basin tracts the ground water falls about 5·2 metres below its maximum height, while in the tract between Minia and Beni Suef, completely under perennial irrigation in 1908, the fall is only 3·0 metres. Wasta and Giza were not thoroughly perennial in 1908. The introduction of perennial irrigation into Upper Egypt has resulted in a rise of ground water of 4 metres, in spite of the fact that the deep trough of the Nile runs down the whole length of the narrow valley.

With the aid of these tables and discharge observations of the basin canals detailed in CHAPTERS IV. and V. and the areas under basin irrigation between Aswan and Assiut we can deduce the following interesting facts:—

The discharge entering the basins between Aswan and Assiut (leaving out the Ibrahimia Canal which irrigates the country to the north of Assiut) in an ordinary year, is 1500 cubic metres per second for forty-five days, while the discharge leaving the basins is 1300 cubic metres per second for twenty days.

| | | Cubic metres. |
|---|---|---|
| Consequently the water entering the basins . . | = | 5,850,000,000 |
| and the water leaving the basins . . . . . | = | 2,250,000,000 |
| Difference | = | 3,600,000,000 |

The basin area is 800,000 acres * or 3,360,000,000 square metres.

The quantity of water evaporated and absorbed is therefore 1·07 metres over the whole area.

The evaporation may be taken as 9·4 millimetres per day for forty-five days or 42 centimetres, leaving 65 centimetres as absorbed in forty-five days.

The forty-five days are counted from 15th August to 30th September. During twenty days of October, until the time of discharge begins and during the time of discharge, the canals give reduced supplies of water to neutralise the losses by evaporation and absorption.

If the rate of absorption in the basins during the twenty days of October is the same as during the previous forty-five days, the depth of water absorbed by the basins will be $\left(65+\frac{20}{45}\times 65\right)$, or 94 centimetres.

There are, in addition to the 800,000 acres of basin land, 100,000 acres of Nile berm and islands, or 900,000 acres altogether. The water given by lift irrigation to the 100,000 acres on the berm may be considered as all evaporated through the plants and may be neglected as far as this calculation is concerned.

A depth of water of 94 centimetres over 800,000 acres means a depth

* We use the word "acre" as synonymous with the Egyptian "feddan."

of 84 centimetres over 900,000 acres. So that the basins supply the ground water under the whole area with 84 centimetres of water.

Now, from careful observation made in 1892 and 1893, while the Aswan reservoir project was being studied, it was found that the direct loss from the Nile between Aswan and Assiut during August and September, or for sixty days, was 300 cubic metres per second. This means a cube of water of 1,560,000,000 cubic metres under a ground area of 900,000 acres or 3,780,000,000 square metres, or 40 centimetres.

The basins supplied 84 centimetres and the Nile directly 40, or 1·24 metres in all. The direct result was a rise of ground water of 5·20 metres. The amount of water needed to saturate one cubic metre of soil was therefore about 24 centimetres.

Now the water rose 5·2 metres in three months, and then fell 3 metres in the two months from 15th November to 15th January, and 2·2 metres in the six months from 15th January to 15th July.

The quantity of water impounded in the ground was 3,780,000,000 × 1·24, or 4,700,000,000 cubic metres. Of this water $\frac{3{\cdot}0}{5{\cdot}2}$, or 2,520,000,000, evaporated, returned to the river, or flowed northwards in the sixty days from 15th November to 15th January at a rate of 490 cubic metres per second; and $\frac{2{\cdot}2}{5{\cdot}2}$ or 2,180,000,000, in the one hundred and eighty days from 15th January to 15th July, at a rate of 140 cubic metres per second, beginning at about 200 cubic metres per second and ending at about 80 cubic metres per second. We consider that a large portion of the ground water from November to January was evaporated by plants and by the ground, but nearly the whole of the ground water between Aswan and Assiut from 15th January to 15th July returned to the Nile and but little went northwards or was evaporated.

Accurate observations made on the quantities of water absorbed and the resulting rise of spring level in the basin tracts would be of more than academic interest, as they would throw a flood of light on the movement of ground water, which is of supreme importance to Lower Egypt.

In addition to the water passing Cairo and utilised at the Barrages, the water which filters into the Rosetta and Damietta branches of the river, and is utilised for irrigation by means of temporary dams thrown annually across the mouths of the rivers, is credited with being equal to a discharge of 40 cubic metres per second as stated in paragraph 10.

12. **Movement of Ground Water.**—Water exists in greater or less amount under the surface of all rocks or soils. It is generally derived from local rainfall, but that found in Egypt north of Aswan is practically all due to seepage from the Nile or its canals and basins. The amount con-

tained in the limestone and other rocks bounding this part of the valley may be neglected for the purpose of this book, and we confine our attention to the water contained in the interstices of the soil.

The laws which govern the flow of underground water are the following. The interstices of the soil may be looked on as forming a series of tubes of capillary size, and the laws of flow in such tubes will apply. These show that the discharge is proportional (1) to the difference of head, (2) to the reciprocal of the length of the tube, and (3) to the fourth power of the diameter. Water moves with comparative rapidity through coarse gravel, less rapidly through sand, much less rapidly through loam, and extremely slowly through clay. The loam of the soil, varying between sand and clay, rests everywhere on a stratum of gravel or coarse sand, which is generally cut into by the river, and the river water flows with comparative freedom along this pervious layer.

When an advancing sheet of underground water meets soils of different degrees of permeability, it will move most freely through the most permeable.

The effect of capillarity is to create a virtual head. The amount of the head varies inversely as the diameter of the pores, and depends also on the nature of the grains and probably also on the salt content of the water. Experiments by the Agricultural School go to show that one metre may be taken as a working limit to this head in average loam. They show also how slowly the water makes its way through clay, and this in spite of the facts that the pores of the clay are finer and the capillarity head will be ultimately higher than in sand. The explanation is to be found in the much greater increase of frictional resistance in clay. It is owing to the fineness of the pores (and consequent high value of the the capillary attraction) that it is extremely difficult to dry clayey soil that has become well saturated with water.

Where the surfaces of two grains are in contact, the capillary attraction is greatest close to the point of contact, and further away may not be enough to sustain the weight of the column of water below. Consequently the water surface will sag here, but will creep up along the narrow parts of the pores. The general surface tangential to these portions where the underground water is in contact with air in the pores is usually termed the saturation level, ground water, spring level, level of subsoil water, or water-table. The action of capillarity, however, does not end there, but causes a film of greater height and of considerable surface to spread upwards towards the roots of plants and the outside air. Under the influence of changes of pressure and temperature, there is a continual in-and-out flow of the air of the soil, and this breathing, combined with ordinary diffusion of the vapour, causes a rapid evaporation of the subsoil water, leaving behind the dissolved salts.

The average thickness of Nile alluvium is about 7 metres,* and below that there is a stratum of diluvial sand and gravel. It is demonstrable that the river cuts into this layer, which therefore transmits the static head of the Nile in flood to great distances. Under its influence the water is forced up through the superincumbent loam, through which it rises in an almost horizontal sheet. When the river falls again and the head is removed the water-table sinks again, horizontally as before.

Simultaneously with the ascent of this sheet, the water percolates from the banks directly into the alluvium, and we have near the river an annual wave superposed on the horizontal water-table, but propagated on the whole horizontally. But so great is the resistance of the alluvium that the crest of the wave never gets far from the bank before the deflux causes the negative wave to set in.

As has been already shown in paragraph 11, the water which enters the soil under pressure or horizontally direct from the Nile is considerably added to by that which descends vertically in the basins during their annual inundation. The calculations at the close of the above paragraph attribute two-thirds to the basin and one-third to the Nile.

The importance of this basin water in feeding the springs came as a surprise to us, but it explains how ground water is raised so steadily and persistently by direct irrigation and high-level irrigation canals traversing sandy soil and loam. It is so easy for the water to descend vertically by gravitation.

The mathematical theory of such waves has been worked out.† It is sufficient to say here that the equation is of the same form as that met with in the conduction of heat, so that known phenomena in the latter may be used to interpret the movement of ground water.‡ The chief points are the following: (1) as a wave is propagated through the medium its amplitude diminishes in geometrical proportion as the distance traversed increases in arithmetical progression; (2) at the same time the epoch, or date of maximum or minimum, is retarded by an amount proportional to the distance traversed; (3) components of short period are more rapidly propagated than those of long period; but (4) their penetration§ is proportionately less, and they die out more rapidly. From these laws we may infer that a flush of one day's duration will penetrate about twenty times as rapidly into the soil as one of the annual flood wave, but will die out in one-twentieth of the distance. The rise and fall of canals, owing to rotations of, say, twenty-three and fifteen days, will penetrate laterally to one-fourth and one-fifth respectively of the distance of the annual wave.

* *The Movements of the Subsoil Water in Upper Egypt*, by H. T. Ferrar, p. 16.

† Hurst, *Cairo Scientific Journal*, vol. vi. p. 27 ; or Boulanger, *Hydraulique générale* (Paris, vol. i. p. 249).

‡ *Encyclopædia Britannica*, 11th edition, vol. vi. p. 894.

§ It varies as the square of the period.

Now, Mr Ferrar has found by observation that the annual wave penetrates to a distance of about one kilometre.* Accordingly we should expect that severe rotations will affect the subsoil water-level to about 200 metres and lighter ones to about 250 metres, and it would take a three months' period in a canal to make the effect felt to a distance of half a kilometre.

There has been much written in Egypt during the last five years on the movement of underground water. Mr H. T. Ferrar, of the Survey Department, has written two reports on the movement of ground water in Lower and Upper Egypt and also papers to the *Cairo Scientific Journal*; while M. Audebeau Bey, of the State Domains Administration, has written three reports on experiments conducted by him. In addition to these have been many other publications, and the Survey Department are conducting further experiments under the direction of Mr B. F. E. Keeling. We shall confine ourselves to the works of Mr Ferrar and Audebeau Bey, as they have been printed and are in our hands.

Mr Ferrar's work on Upper Egypt gives numerous cross sections showing the fluctuations of the ground water at different places between Aswan and Cairo. From these the sections for Girga and Minia are taken.

The table at the top of page 419 shows how the steady rise of the water surface at the Delta Barrage (Table 190) has raised the level of water in the Cairo wells. (See also pages 32, 99, 341, and 415.)

* Ferrar, *op. cit.* p. 38.

[Table.

TABLE 48.—MOVEMENTS OF GROUND WATER, GIRGA.

| No. | Date. | Bath Well. | Cupola Well. | Sakia. El Washif. | Sakia El Omda (2). | Sakia El Omda (1). | Sakia Abd el Megid. | Sakia F. Ismain. | Sakia Mh. Hassan. | Bir Ahmed Telahi. | Bir H. Awamer. | Sakia Muki. | Sakia A. Abdalla (S) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 62·79 R.L. of B.M. | 63·92 R.L. of B.M. | 63·12 R.L. of B.M. | 62·80 R.L. of B.M. | 63·40 R.L. of B.M. | 63·28 R.L. of B.M. | 63·47 R.L. of B.M. | 63·23 R.L. of B.M. | 63·24 R.L. of B.M. | 62·59 R.L. of B.M. | 62·87 R.L. of B.M. | 63·35 R.L. of B.M. |
| | 1907. | | | | | | | | | | | | |
| 1. | December 19 . | 59·71 | 60·89 | 61·05 | (60·92) | 60·93 | 60·88 | 60·99 | 61·05 | 60·10 | 60·62 | 60·94 | 60·77 |
| | 1908. | | | | | | | | | | | | |
| 2. | January 18 . | 59·39 | 60·59 | 60·64 | 60·64 | 60·64 | 60·54 | 60·64 | 60·62 | 60·46 | 60·19 | 60·53 | (59·65) |
| 3. | March 21 . | 59·02 | 60·05 | 60·00 | 59·98 | (58·94) | (58·24) | 59·77 | (58·02) | 58·58 | 59·26 | 59·27 | 59·21 |
| 4. | July 9 . | 57·29 | 57·74 | 57·70 | 57·58 | (56·15) | (55·72) | Dry | (55·38) | (56·00) | 56·56 | (55·84) | 56·68 |
| 5. | August 4 . | 57·30 | 57·61 | ... | 57·37 | 56·30 | In use | ,, | Pipe spurting | 55·99 | 56·32 | In use | 56·46 |
| 6. | ,, 29 . | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash | Hod awash |
| 7. | November 9 . | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | ,, | 62·99 | 62·84 |
| 8. | December 16 . | 60·85 | 61·57 | 61·14 | 61·54 | 61·65 | 62·02 | Mark gone | 61·77 | 61·70 | 61·32 | 61·64 | 61·59 |

TABLE 48.—*continued.*

| No. | Date. | Sakia Moh. Hamad (N). | Sakia E. Kashef. | Sakia Hag Mazuk. | Old Sakia. | Sakia Azm. | Bir Mh. Ziedan. | River. | Bir Mh. Ziedan. (South).† | Bir el Suk.† | Bir Megembe.† | Station Well.† | Rest Ho. Well.† | Bank Well. (North).† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 63·25 R.L. of B.M. | 63·43 R.L. of B.M. | 64·28 R.L. of B.M. | (64·80) R.L. of B.M. | 64·80 R.L. of B.M. | 64·12 R.L. of B.M. | 64·98 R.L. of B.M. | 64·12 R.L. of B.M. | 64·49 R.L. of B.M. | 63·57 R.L. of B.M. | 64·57 R.L. of B.M. | 64·09 R.L. of B.M. | 63·70 R.L. of B.M. |
| | 1907. | | | | | | | | | | | | | |
| 1. | December 19 . | (60·04) | (59·01) | 60·66 | 60·66 | 60·34 | 59·95 | 58·79 | 59·95 | 59·79 | 59·57 | 59·47 | 59·37 | 59·39 |
| | 1908. | | | | | | | | | | | | | |
| 2. | January 18 . | 60·11 | 60·20 | 60·04 | 60·03 | (58·82) | 59·42 | 58·48 | 59·42 | 59·31 | 59·11 | 59·05 | 58·98 | 59·00 |
| 3. | March 21 . | 59·18 | 59·13 | 58·94 | → * | (57·97) | 58·31 | ... | 58·31 | 58·22 | 57·81 | 57·51 | 57·86 | 57·90 |
| 4. | July 9 . | 57·27 | 56·88 | (56·12) | 57·10 | 57·14 | 56·79 | (55·36) | 56·79 | 56·79 | 56·85 | 56·77 | 56·99 | 57·03 |
| 5. | August 4 . | 56·54 | 56·62 | In use | Mud (56·92) | In use | 57·02 | 59·48 | 57·02 | 57·29 | 56·94 | 57·50 | 57·77 | 57·58 |
| 6. | ,, 29 . | Hod awash | Hod awash | 60·18 | 59·82 | 60·78 | 61·03 | 63·72 | 61·03 | 61·16 | 61·16 | 61·55 | 61·94 | 61·91 |
| 7. | November 9 . | 62·91 | 62·77 | 63·02 | 62·90 | 62·78 | 62·90 | 61·40 | 62 90 | 62·62 | (62·26) | 62·40 | 62·28 | 62·27 |
| 8. | December 16 . | 61·50 | 61·54 | 61·74 | 61·50 | (60·60) | 60·92 | 58·94 | 60·92 | 60·24 ‡ | 60·46 | 60·12 | 60·30 | 60·31 |

*N.B.*—Figures in parentheses indicate external influences, such as use, affecting the readings.
* Interpolated the B.M. † Wells in order from south to north. ‡ B.M. moved.

TABLE 49.—MOVEMENTS OF GROUND WATER, TAHTA.

| No. | Date. | Sakia S. Mh. Amran. | Sakia (old) Ethman. | Sakia Gadalla (N). | Sakia Abu Talib. (Mid). | Sakia Tergawi (S). | Canal Sohagia. | Sakia Rest Ho. | Sakia Abu Zeit. | Bir Ali Eff. | Sakia A. Mahmud. | Bridge, 2nd. | Sakia Ali Ahmed. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 55·77 R.L. of B.M. | 55·33 R.L. of B.M. | 55·93 R.L. of B.M. | 55·46 R.L. of B.M. | 55·35 R.L. of B.M. | 58·80 R.L. of B.M. | 55·67 R.L. of B.M. | 55·34 R.L. of B.M. | 55·54 R.L. of B.M. | 55·06 R.L. of B.M. | 57·05 R.L. of B.M. | 55·33 R.L. of B.M. |
| | 1908. | | | | | | | | | | | | |
| 1. | January 31 . | (50·18) | 51·83 | 51·67 | 51·69 | 51·90 | 51·47 | 51·81 | 51·76 | 51·71 | 51·64 | 52·88 | 51·88 |
| 2. | March 20 . | (48·50) | 51·13 | 51·21 | (49·42) | 51·32 | 51·26 | 51·38 | (49·28) | 51·04 | 51·17 | 52·05 | (50·53) |
| 3. | July 11 . | (48·02) | (47·80) | (48·13) | (47·94) | (49·09) | 49·51 | 49·71 | (48·12) | 49·27 | (48·76) | Dry | (48·15) |
| 4. | August 6 . | 49·66 | 49·32 | 49·35 | 49·37 | 49·55 | 49·52 | 49·45 | 49·43 | 49·10 | 49·33 | ... | 49·17 |
| 5. | September 1 . | 52·35 | 52·02 | 52·13 | ... | ... | 55·45 | 52·09 | 55·39 * | ... | ... | 55·23 | |
| 6. | November 11 . | 54·37 | 54·28 | 53·91 | 54·06 | 54·01 | 54·52 | 55·07 | 53·93 | 53·79 | 53·98 | 54·05 | 54·13 |
| 7. | December 18 . | 53·16 | 52·93 | 52·68 | 52·66 | 52·86 | 53·90 | 53·44 | 52·81 | 52·64 | 52·80 | 53·85 | 52·89 |

TABLE 49.—*continued.*

| No. | Date. | Sakia Abdalla Bey. | Bridge, 1st. | Bir Mh. Suliman. | Sakia Ali Mufta. | Bir Said Omar. | Bir El Halim. | Bir Salman. | Bir Hermina. | Bir Abu Kalifa. | Sakia Khalil. | River. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 55·45 R.L. of B.M. | 57·08 R.L. of B.M. | 56·51 R.L. of B.M. | 55·83 R.L. of B.M. | 56·62 R.L. of B.M. | 58·27 R.L. of B.M. | 58·59 R.L. of B.M. | 57·10 R.L. of B.M. | 57·90 R.L. of B.M. | 57·26 R.L. of B.M. | 56·31 R.L. of B.M. |
| | 1908. | | | | | | | | | | | |
| 1. | January 31 . | 52·15 | Puddles | 51·71 | 51·83 | (51·55) | 52·58 | 52·65 | 52·66 | 52·62 | 52·42 | 51·30 |
| 2. | March 20 . | 50·96 | ... | 50·30 | 50·23 | (49·74) | 51·25 | 51·59 | 51·64 | 51·66 | (51·30) | |
| 3. | July 11 . | (48·22) | Dry | 48·31 | (47·45) | 47·92 | 49·22 | 49·58 | 49·38 | Dry | | |
| 4. | August 6 . | 49·17 | ,, | 48·02 | In use | 48·68 | 49·47 | 49·46 | 49·75 | ,, | In use | 53·52 |
| 5. | September 1 . | ... | ... | 54·08 | Awash | 55·62 * | 54·92 | 56·14 | Awash | 55·52 | Fed by canal | 56·54 |
| 6. | November 11 . | 54·36 | 53·50 | 54·16 | 54·68 | 54·72 | 55·55 | 55·60 | 55·69 | 55·68 | 55·61 | |
| 7. | December 18 . | 53·19 | 53·21 | 52·95 | 53·05 | 51·96 | 54·08 | 54·01 | 54·06 | 54·02 | 54·14 | (51·66)† |

*N.B.*—Figures in parentheses indicate external influences, such as use, affecting the readings.

* Awash. † B.M. moved.

TABLE 50.—MOVEMENTS OF GROUND WATER, MINIA.

| No. | Date. | Pool. | Bahr Yusuf. | Sakia Han Argub. | 9th bridge. | 6th bridge. | 4th bridge. | 3rd bridge. |
|---|---|---|---|---|---|---|---|---|
| | | ... | 39·83 R.L. of B.M. | 39·61 R.L. of B.M. | 40·51 R.L. of B.M. | 38·61 R.L. of B.M. | 40·09 R.L. of B.M. | 38·43 R.L. of B.M. |
| | 1908. | | | | | | | |
| 1. | February 26 | 36·89 | 35·83 | 36·61 | 37·31 | 36·76 | 37·24 | 35·94 |
| 2. | March 25 | | | | | | | |
| 3. | July 13 | | | | | | | |
| 4. | August 10 | | | | | | | |
| 5. | September 4 | | | | | | | |
| 6. | November 13 | ... | ... | ... | ... | ... | ... | 36·80 |
| 7. | December 21 | ... | ... | ... | ... | ... | ... | 36·74 |

TABLE 50.—*continued.*

| No. | Date. | Bir Gama Gagia. | Bir Junias Makhluf. | Bir Nagar Yusuf. | Canal bridge. | Ibrahimia canal. | Bir Masaud. | River. |
|---|---|---|---|---|---|---|---|---|
| | | 43·66 R.L. of B.M. | 45·17 R.L. of B.M. | 39·48 R.L. of B.M. | 42·06 R.L. of B.M. | 41·31 R.L. of B.M. | 44·72 R.L. of B.M. | 39·62 R.L. of B.M. |
| | 1908. | | | | | | | |
| 1. | February 26 | 36·61 | 36·54 | 37·63 | 40·11 | 40·18 | 34·74 | 32·75 |
| 2. | March 25 | 36·49 | 36·47 | 37·88 | ... | 40·53 | 34·50 | 32·33 |
| 3. | July 13 | 35·69 | 35·67 | 34·68 | 38·77 | 38·70 | 33·78 | 32·25 |
| 4. | August 10 | 35·94 | 35·94 | 35·46 | ... | 40·28 | 33·88 | 35·90 |
| 5. | September 4 | 36·96 | 36·92 | 37·68 | ... | 40·76 | 35·78 | 39·58 |
| 6. | November 13 | 37·81 | 37·78 | 38·11 | ... | 40·38 | 37·32 | |
| 7. | December 21 | 37·43 | 37·36 | 38·08 | 40·32 | 40·37 | 36·04 | 34·97 |

Girga and Tahta are in the basin tracts, and Minia is perennially irrigated. Of these Mr Ferrar writes:—

"Having shown that the Nile water has easy access to the diluvial sands at low stage, it is only necessary to mention the additional means by which this water enters these sands during the flood.

Though the river is in contact with the sands or gravels on its banks during the greater part of the year, during flood this contact must be more intimate; at this time the water will readily soak down into the diluvial beds along the edges of the basins used in flood irrigation, and ingress is also made by the numerous sakia-pits all over the country. For instance, at Kift a stream of flood water was seen flowing into a sakia-pit without raising the level of the water in it, and if this takes place at every sakia which is submerged during flood-time, the quantity of water which passes into the diluvial beds by this means must be very great.*

In the main, therefore, the water which passes into Egypt past Aswan remains in the valley, and is distributed in the following ways:—

(1) It passes into Lower Egypt as an open river.

(2) It passes into Lower Egypt by way of the porous sands and gravels underlying the Nile mud.

(3) It is evaporated from the river and from the surface of the land.

(4) It is poured upon the land for agricultural purposes.

(5) It is carried into the Fayum depression by the Bahr Yusuf.

(6) It passes into the crevices of the older rocks, but the extent to which this takes place is, as yet, unknown, and the quantity which is returned to the Nile is also unknown.

(7) And, finally, it filters in and out of the younger strata, according to season.

It is with the last of these movements of the water that we are now concerned.

The Girga water-table curves are remarkable for their similarity and regularity, and show that the valley-fill in this locality has been laid down uniformly. The angles at which the traces of the water-table meet the almost vertical river bank are enough to show that the Nile mud at Girga is relatively porous, and the rapid rise of the water-table during the month of August agrees with this deduction. At Sohag the water-table sinks down to lowest Nile level, and its rise and fall is 7 metres, that is, a metre more than at Girga. This greater range, due no doubt to the greater fall of the water-table, the conspicuous flatness of the curves, and the small difference of level between water-table and river surface, point to the presence of very porous strata. The way in which the water-table rises shows that the deposits beneath Sohag are coarse and like the gravels and sands which are visible in the river bank opposite this town.

During the summer, the water-levels in the Sohagia Canal at Tahta, the Bahr Yusuf at Minia, and the Bahr Lebeini at Giza were lower than the levels of the water-table in each neighbourhood respectively, which proves that these canals act as drains. The depression which hugs the Western Desert edge on the left side of the valley, at Sohag, has given some unusual and therefore interesting data. This depression holds water during the greater part of the year, and thus keeps the

* To-day there are 40,600 sakias in the fields in the basin tracts.

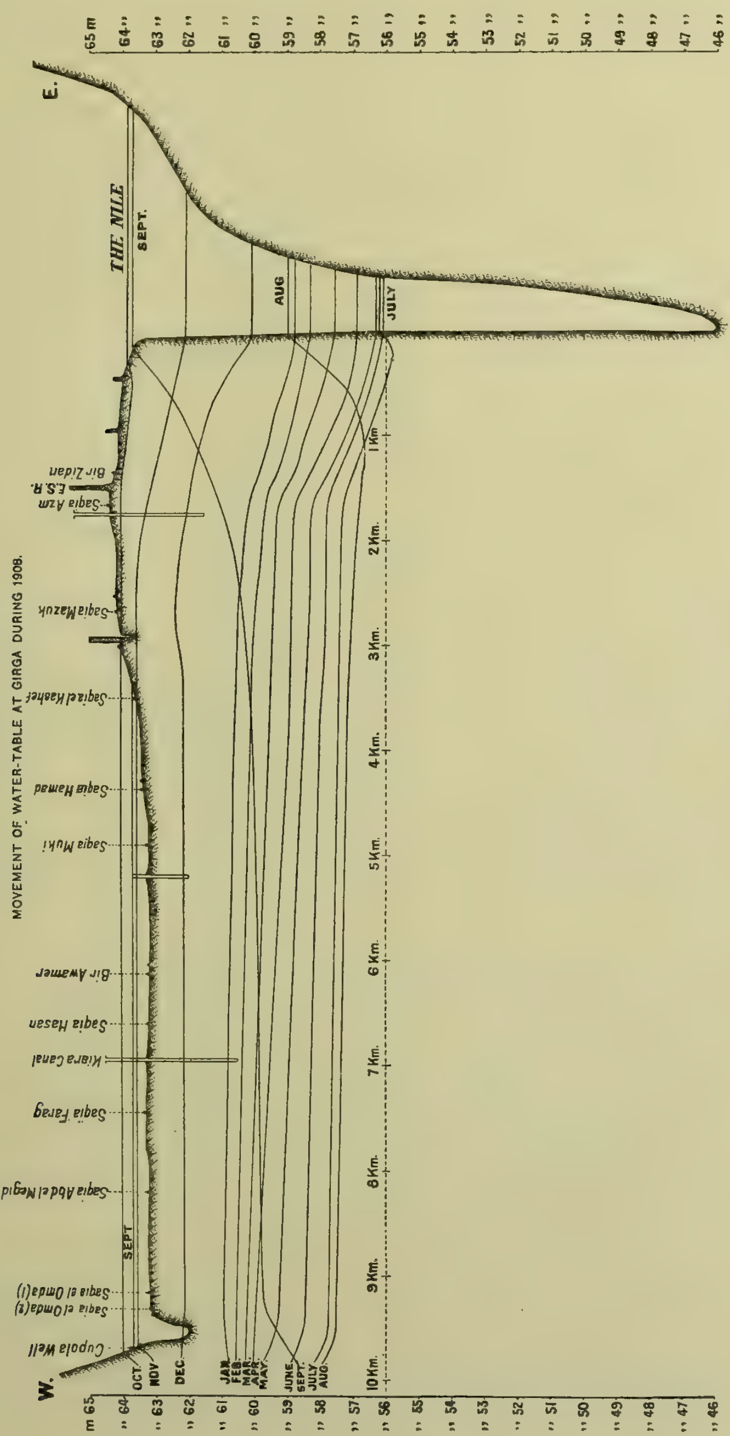

MOVEMENT OF WATER-TABLE AT GIRGA DURING 1908.
THE NILE
E.
W.
SEPT.
AUG
JULY
Bir Zidan
E.S.R.
Sagia Azm
Sagia Mazuk
Sagia el Kashef
Sagia Hamad
Sagia Muki
Bir Awamer
Sagia Hasan
Kiara Canal
Sagia Farag
Sagia Abd el Megid
Sagia el Omda (1)
Sagia el Omda (2)
Cupola Well
OCT.
NOV
DEC.
JAN.
FEB.
MAR.
APR.
MAY.
JUNE
SEPT.
JULY.
AUG.
1 Km.
2 Km.
3 Km.
4 Km.
5 Km.
6 Km.
7 Km.
8 Km.
9 Km.
10 Km.
65 m
64 „
63 „
62 „
61 „
60 „
59 „
58 „
57 „
56 „
55 „
54 „
53 „
52 „
51 „
50 „
49 „
48 „
47 „
46 „

FIG. 1.

water-table high during the spring, but, after this water drains away, the water-table sinks to a level which in parts is lower than the lowest level reached by the river.

The high positions of the water-table at Minia and Beni Suef, and the deterioration of the land at Minia would seem to show that finer deposits of silt have been laid down in this broad stretch of the valley than in the narrower belt at Wasta, where the water-table is seen to be much lower, and to slope steeply towards the river. The borings which have been made in the Beni Suef area show that the modern alluvium is less than 10 metres thick, and contains patches of sand. The diagrammatic section of the valley shows how these porous patches may occur quite frequently throughout the length of Upper Egypt.

At Giza, during the five months, April, May, June, July, and August, it is of great interest to see that the water-table sagged at the centre, and remained at a level which was below that of the Nile at Roda Bridge. Something of this kind was noticed in 1906, when, with reference to Giza, it is stated that 'the rate of fall is greater the further the well is situated from the river, which is in direct opposition to what might naturally be expected.' The simplest explanation of this phenomenon is that, aided by the increased width of the valley, the subsoil water finds an easy escape towards the Delta by means of the porous sands which borings have proved to predominate to the northward. In America it has been found that pumps drawing their water from sands and gravels reduce the level of the water-table in their immediate neighbourhood by some 5 or 6 metres when the supply from below apparently balances the demand. As yet, no data are available to show how far this depression-effect extends away from the well. The water companies of Cairo and Assiut have noticed that during pumping operations a point of equilibrium is approached, but little is known as to the diameter of the depression-curve which is created. A case was noticed at Sohag where a steam pump reduced by 13 centimetres the water-level of a well 200 metres distant. This is a question of considerable importance, but it remains to be discovered from what direction a new supply of water approaches the pump, and what is the radius of action of that pump.

Tahta showed that the ancient channel of the Sohagia Canal did not materially affect the movement of the subsoil water in a great basin.

The plotted water-table curves show that locally there are great differences in the permeability of the alluvium, and that in some cases the underflow is such as to cause the level of saturation to be lower than the river surface in the neighbourhood. Gravels have been found to occur more abundantly than was supposed, with the result that sakia-cultivation is made easy by their occurrence. The comparative impermeability of the Nile mud cuts off the flood-water from the subsoil water, and by doing so prevents the water-table from being raised as soon as the basins commence to fill.

Seepage from canals in the basin-lands of Upper Egypt was seldom noted, but during the summer some flood-canals, such as the Sohagia at Tahta, and the Bahabshin at Beni Suef, acted as drains, and by collecting return-seepage, they tend to lower the water-table and improve the soil. Clear pools of brown seepage water were seen near Naga Hammadi and near Minia, and brought to mind similar pools in Lower Egypt which have been referred to by Sir William Willcocks. Seepage through the Nile safety-banks and through the banks of new perennial canals with

MOVEMENT OF WATER-TABLE AT MINIA DURING 1908.

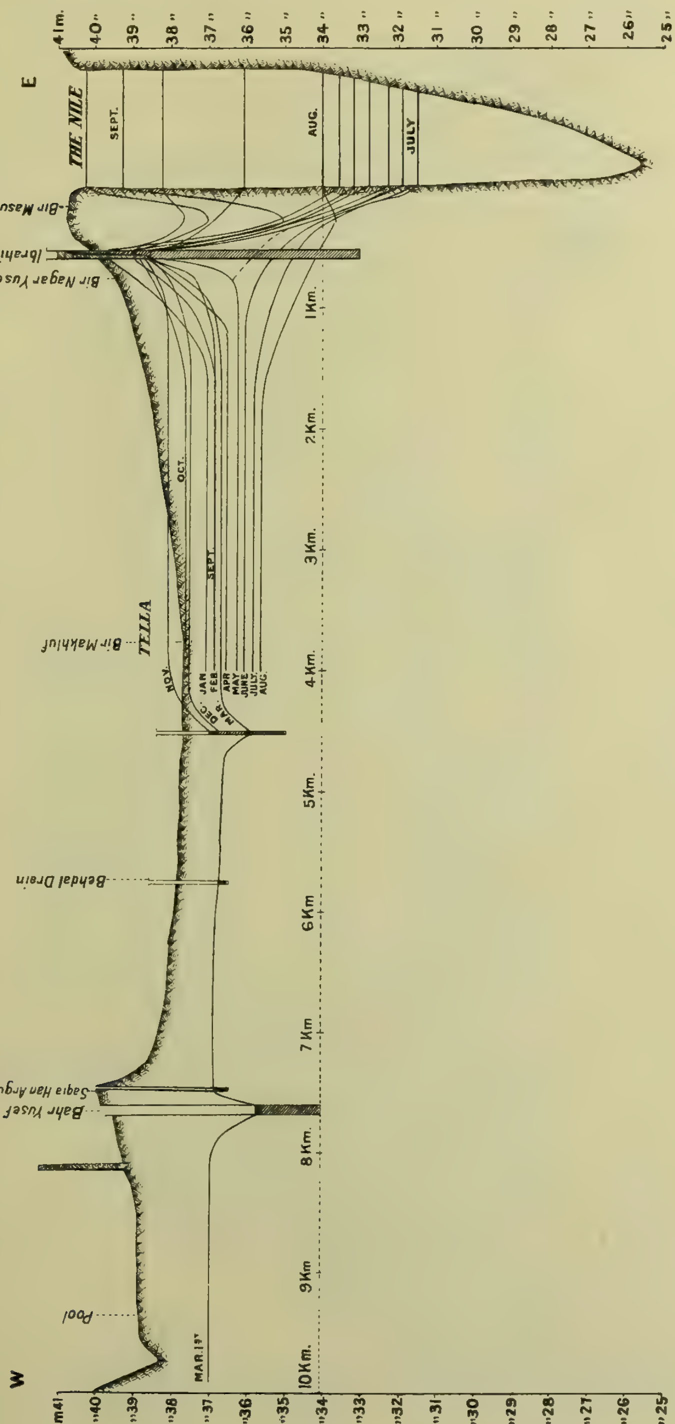



FIG. 2.

DIAGRAMMATIC SECTION ACROSS THE NILE VALLEY AT BENI SUEF.

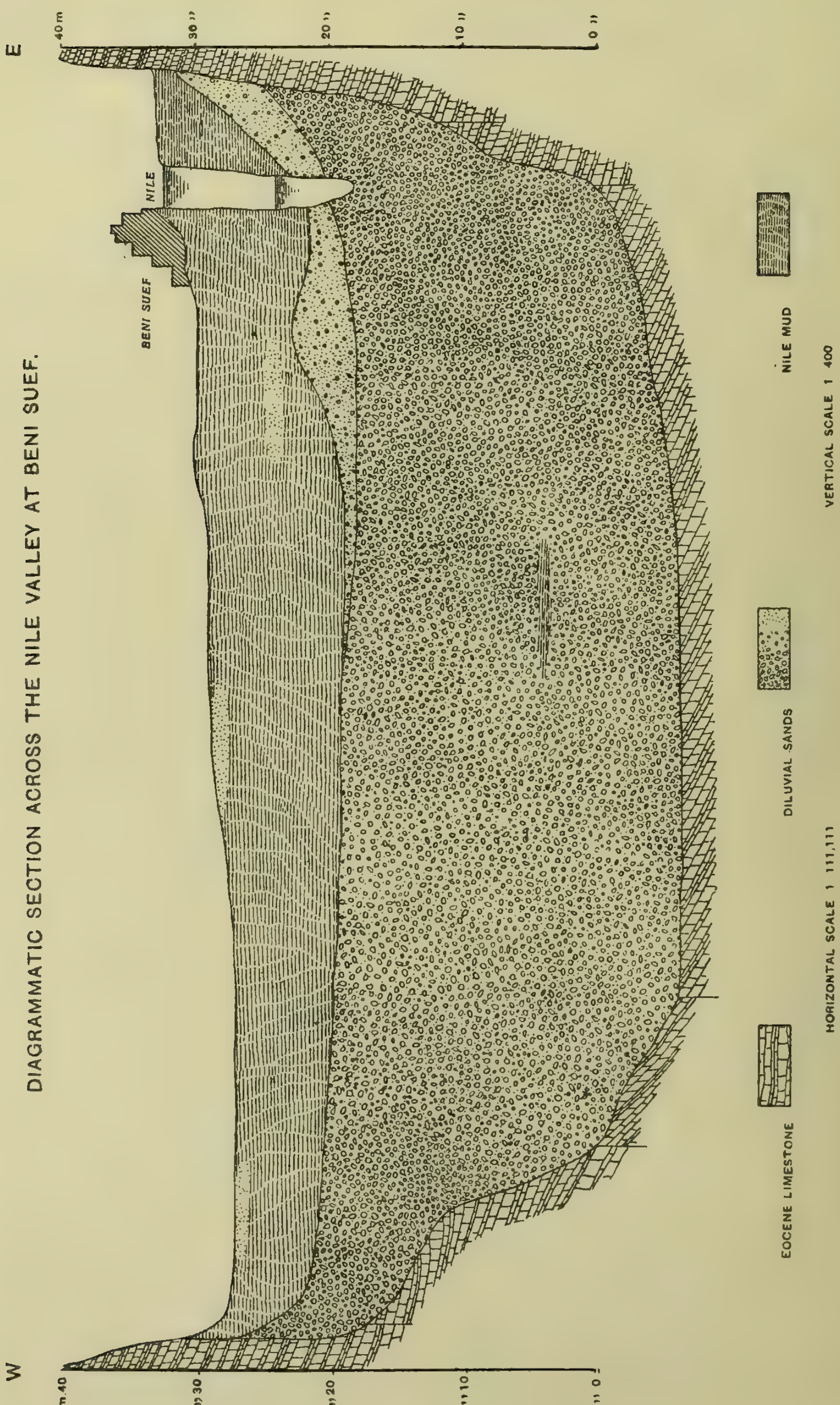
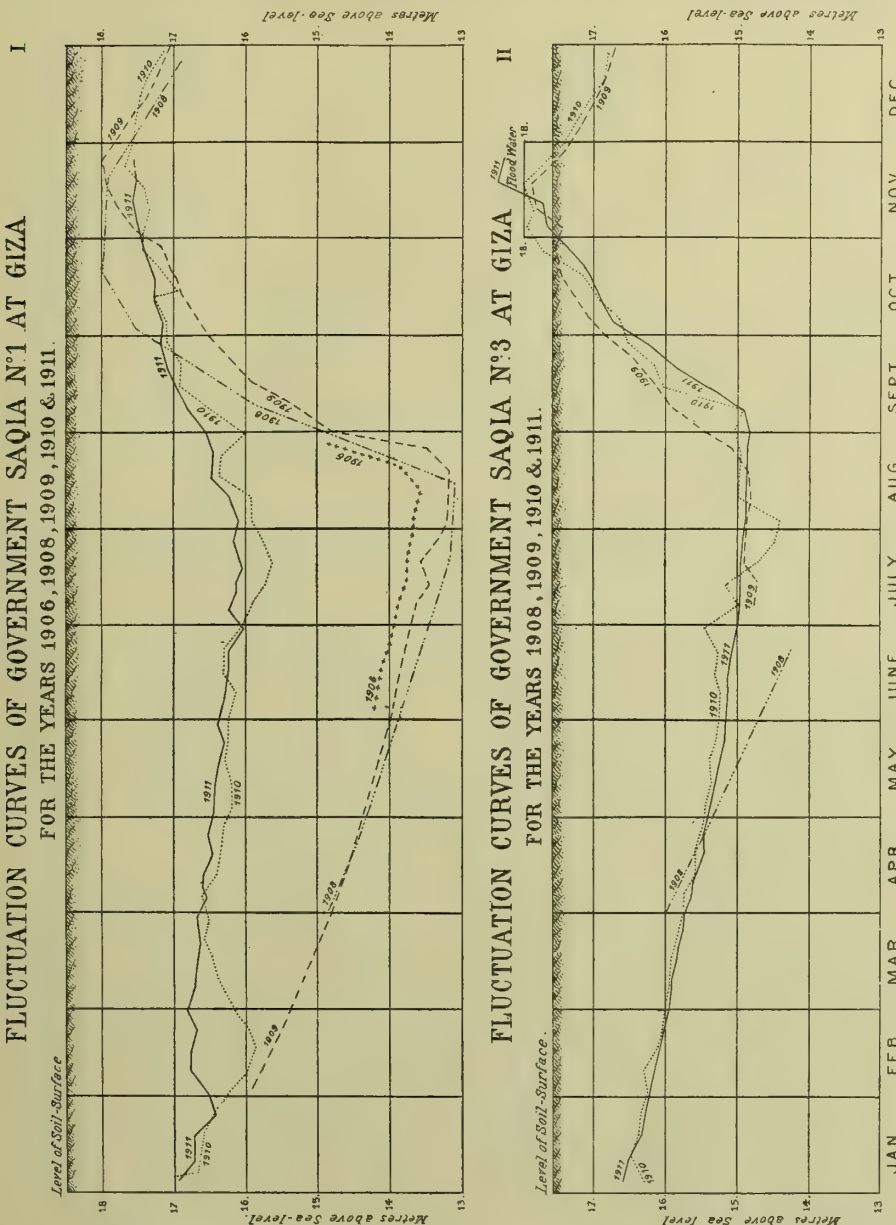



FIG. 3.

high bed-levels, gave rise to salty patches and to pools of water which damaged the growing crops. The salty stretches of land, the pools of water, and the dead and




FIGS. 4 and 5.

dying crops at such places as Minia and Wasta, and in the newly converted basin-lands near Badrashein, show that this evil is growing and covering wide areas.

In the basin-lands, the only striking elevation of the water-table caused by canals or by artificial irrigation, was seen at Naga Hammadi, where the Sugar Refining

Company pump up water for cultivating crops which require a perennial supply. The alteration in height is small, and is not likely to have serious consequences, for pumped water costs money, and therefore will not be wasted. Three sets of observations have been obtained in the perennially irrigated tracts of Upper Egypt, and these sets agree well with one another, and disagree in a very marked manner with those collected in the basin-lands further to the south. They show that periodic rising of the water-heights of the canals and also periodic watering of the crops both cause a temporary rise in the level of the subsoil water. By the small annual range of fluctuation, and by the difference of level between the lowest minimum position of the water-table and the lowest level of the Nile, we are led to the conclusion that the water-table has been raised permanently a height of nearly 4 metres.

The curves show that the water-table, after the bad flood of 1907, was approximately 1 metre lower than after the copious flood of 1908. It is regrettable that we do not possess a knowledge of the position of the water-table as it was ten or fifteen years ago, as this knowledge would be of great value for purposes of comparison, and would provide a measure of the rate at which the water-table is rising. A high flood is followed by a good low stage supply; this beneficial result is due largely to the consequent extra quantity of return-seepage water which is available.

The free water-supplies of the sakias on the Eastern Desert edge, and the apparently abnormal quantities of water on the Western Desert edge, are not due to local springs, but are derived from the single and finite body of Nile infiltration water. Most sakia-pits obtain a ready supply of water from the porous sands and gravels, and sometimes an artificial head is created, which has given rise to the erroneous belief that artesian conditions exist in Upper Egypt. No such wells are known, but this investigation has shown that it is convenient to classify the existing wells into classes called desert, basin, and riverain. These classes agree with the topographical features suggested by the terms, and show that the water-table may be regarded as made up of three zones of fluctuations which are parallel to the several reaches of the river, and whose outer limits are the outer limits of the valley-fill, namely, the solid rock formations of the Nile valley trough.

By recognising three zones of fluctuation, we gain some idea as to the direction of movement of the subsoil water. The riverain zone is about a kilometre broad, and the water-levels of the wells situated on it show a fluctuation which is inversely proportional to the distance from the river. According to season, Nile water filters into and out of this zone in a direction nearly perpendicular to the river bank. The basin zone lies mainly beneath the basin lands, both converted and unconverted, and occupies an area slightly less than the cultivated area of Upper Egypt. The water-levels of the wells in this great zone rise and fall as if actuated by an annual tide. They begin to rise simultaneously with one another, some forty-five days after the flood has reached Egypt, and attain a maximum after the crest of the flood has passed. The water in this zone would seem to move in a direction parallel to the several reaches of the Nile, but no positive evidence has been obtained to support this view. Nor do we know the direction of movement of the water in the desert zone; but hydraulic considerations suggest that the water moves inwards and outwards diagonally—that is, north-east and north-west towards the east and west sides of the valley respectively during flood, and north-west and north-east from the east and west sides respectively after the flood has passed."

The following selection is from a paper contributed by Mr Ferrar to the *Cairo Scientific Journal*, July 1910, "On the Creation of an Artificial Water-Table in Egypt":—

"The head of water in deep wells provides only a measure of the pressure which exists between the bottom of the well and the source of the water or the nearest point at which the Nile water is able to enter readily the porous diluvial beds. Should an impermeable stratum, for instance a bed of clay, be interposed, the magnitude of this hydrostatic pressure will be reduced owing to increased friction, and a diminished head of water will be observed.

This is represented in the composite diagram (fig. 6), where a few of the experimental tube-wells of the Survey Department, which have been selected from a great number now under observation in Lower Egypt, are drawn as if they had been put down in neighbouring fields. Of these, No. 13 Sh. pierces an impermeable bed of clay 13 metres in thickness and enters the diluvial sands; D. No. 8 passes downwards into the clay, to a point below the minimum position of the water-table; No. A is not deep enough to pass into that portion of the alluvium which is saturated and drained annually. The horizontal lines drawn in the wells represent the range of fluctuation of the water-heights which have been measured in each well. The water in well No. 13 Sh. rises upwards from the minimum position of the water-table to a height which is above the level of natural saturation, owing to the well being in connection with the river through the coarse underlying strata, and the tube providing an almost frictionless channel up which the water mounts. The water in D. No. 8 does not rise so high, for the pressure is reduced owing to the friction caused by the 8 metres of clay which intervene between the bottom of the well and the porous gravels. No. A is expected to contain water only during the time the water-table is an appreciable height above its maximum position, but when it does so, the water may rise higher than the real upper surface of saturation, though not so high as in the former well, for the increased thickness of intervening clay would introduce increased friction and consequent loss of head. No. B has been shown as if it were bored no deeper than to the position assumed by the real surface of saturation at maximum water-table epoch. The water in this well should show the true maximum position of the natural water-table at this point. No. 21 H does not reach this maximum position and therefore will remain dry throughout the year, unless water is added from above. In striking constrast to this last well is tube-well No. 22 R, which is separated from the river by the usual safety-bank, but penetrates into the lower diluvial sands: during October the Nile-flood pressure caused a continuous stream of water to bubble over the top of the pipe as if it were a true artesian well. The minimum water-heights in the wells should give the true minimum position of the natural water-table."

Birch Pasha, the Administrator of the State Domains, has published three reports by M. Audebeau Bey on *The Subsoil Water of Egypt and its Influence on the Cotton Crop.* These reports are dated 1909, 1910, and 1911. From the report of 1909 we extract:—

"In 1884 the level at which the water was held up at the Barrage was raised from a mean of R.L. 12·00 to R.L. 13·00 metres, and in 1889 Sir W. Willcocks

## Composite Diagram

Showing the artificial water-table supported in places by an unsaturated lenticle of impermeable clay

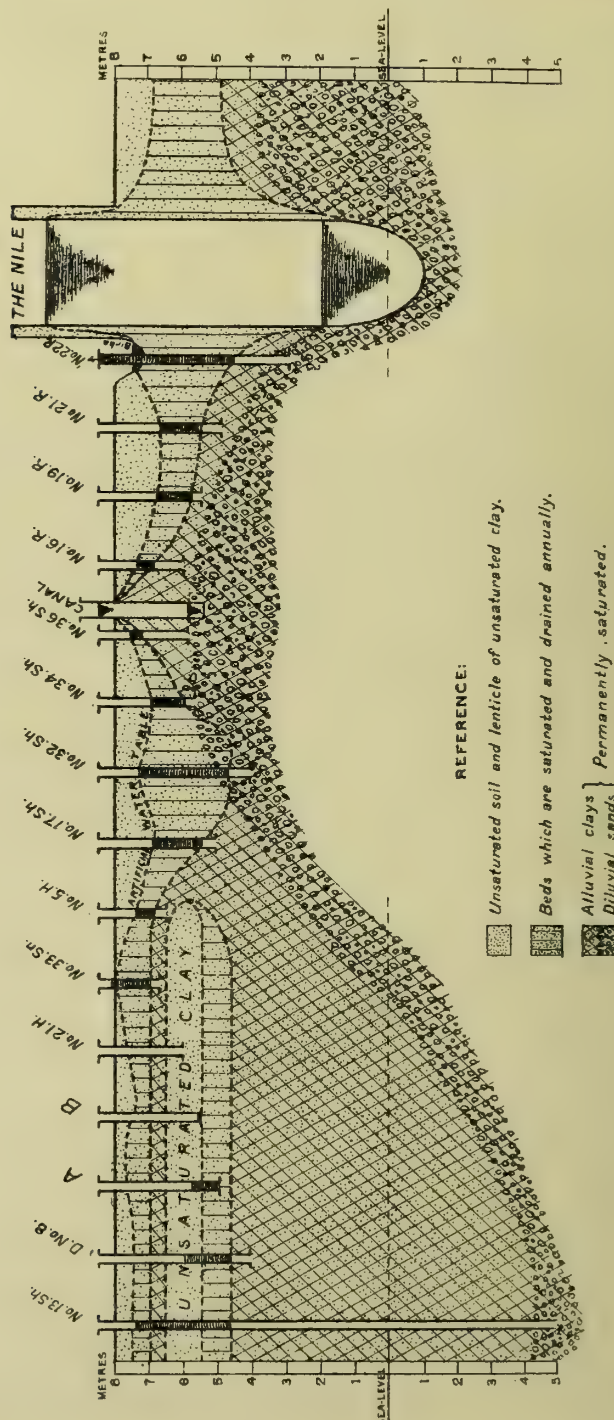



Fig. 6.

recorded that the subsoil water in Southern Menufia had risen everywhere 1 metre. Since then the level of the Barrage was raised to a maximum of R.L. 14·00 metres in 1890 and to R.L. 15·50 in 1900. The summer levels of all the canals in the Delta have been gradually raised, until at the present time there is not much difference between high-flood level and summer level.

Everything goes to prove that towards the end of the nineteenth century the subsoil water-level in June and July was 5 or 6 metres below the ground at the southern end of the Delta, and from my own observations it was in our Santa estate, in the heart of the Delta, 3 to 5 metres below ground-level according as the land was under crop or lying fallow.

Judging from the level of the subsoil water now recorded, we note that the level in the months of June and July was from 1 to 2 metres below the level of the land under crop, and from $1\frac{1}{2}$ to $2\frac{1}{2}$ below uncultivated land. Under the action of the flood the subsoil water was raised about 1 metre, coming in many places to the surface of the ground. (See pages 32, 86, 341, and 419.)

The Shebin canal in 1909 at our pumping stations was 2·4 metres higher on the 10th July and 1·8 metres higher on the 21st July than on these dates in 1901, when observations were recorded for testing the pumps. This rise of water-level in the canals has brought the subsoil water near the surface of the ground, which is here generally a sandy loam, with disastrous effects on the yield of cotton."

M. Audebeau Bey has kindly written a résumé of his reports as far as the movement of subsoil water is concerned, and we here give a translation :—

"Soundings have disclosed the fact that gravel and sand overlie the rocky substratum of the Nile Valley. Above them are superimposed strata of sand and alluvium more or less clayey. In some places the sands and gravels come to the surface of the ground ; while in others, and especially near the Mediterranean, they may lie even 50 metres below ground level. Experience has proved their great porosity.

The subsoil water of the deep sand and gravel strata is utilised for the water supply of towns and for purposes of irrigation in Upper and Middle Egypt, and in the southern and central parts of the Delta. As one advances, however, northwards, and is within 50 or 60 kilometres of the Mediterranean, this subsoil water becomes brackish or saline and is not used for irrigation.

When impermeable strata overlie the sand and gravel stratum, we meet with a subsoil water in the upper alluvial strata which has nothing to do with the subsoil water that saturates the sands and gravels. The fluctuations and movements of these two waters have nothing in common.

Between the strata which are perfectly permeable and impermeable vertically, there necessarily exists a large number of strata of different degrees of porosity.

We call the subsoil water of the deep sands and gravels natural, while that of the upper permeable strata is called artificial.

Natural Subsoil Water.—The height of the water-table of this natural subsoil water has been continuously observed in deep bores (wrongly called artesian); and also in sakias in the fields, removed far from canals, and that at times when they are not being worked. The State Domains Administration possesses in Lower Egypt many wells 40 and 50 metres deep, some in directions running north and south, and others in directions running east and west. The Administration has

therefore been able to study the movements of the water-table of this subsoil water by daily records of gauges kept for a number of years.

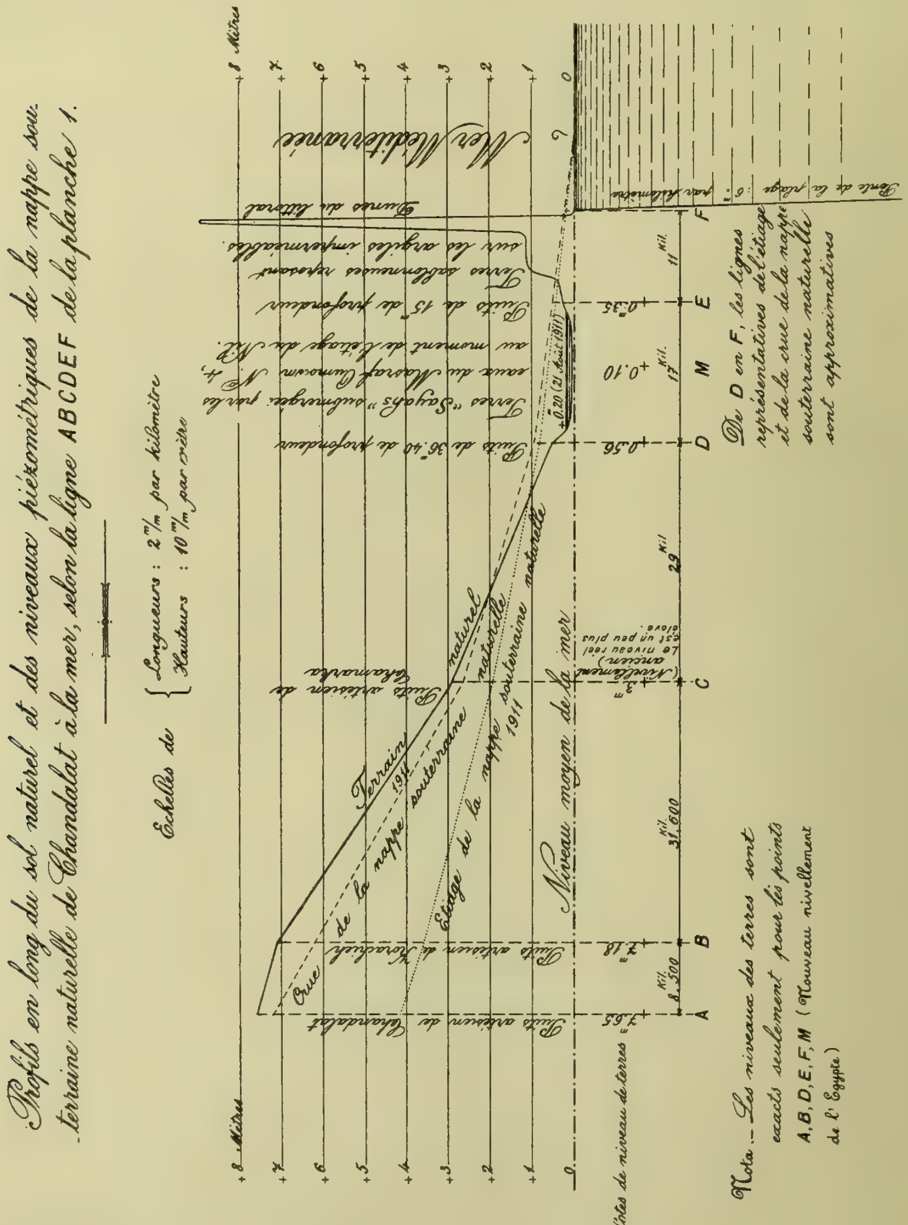


FIG. 7.

Observations prove that the natural water-table, in its main movements, moves up and down with the Nile. The times of high and low levels are later than those of the Nile. The delay is greater the farther one moves away from the Rosetta and Damietta branches of the Nile and the nearer one gets to the sea. Thus in

the catacombs of Alexandria the retardation amounts to four months. The annual fluctuation is greater in years of high flood than in those of low flood (provided the levels of the river have not been interfered with by Barrages). The amount of fluctuation diminishes as one moves away from the two branches or goes northwards.

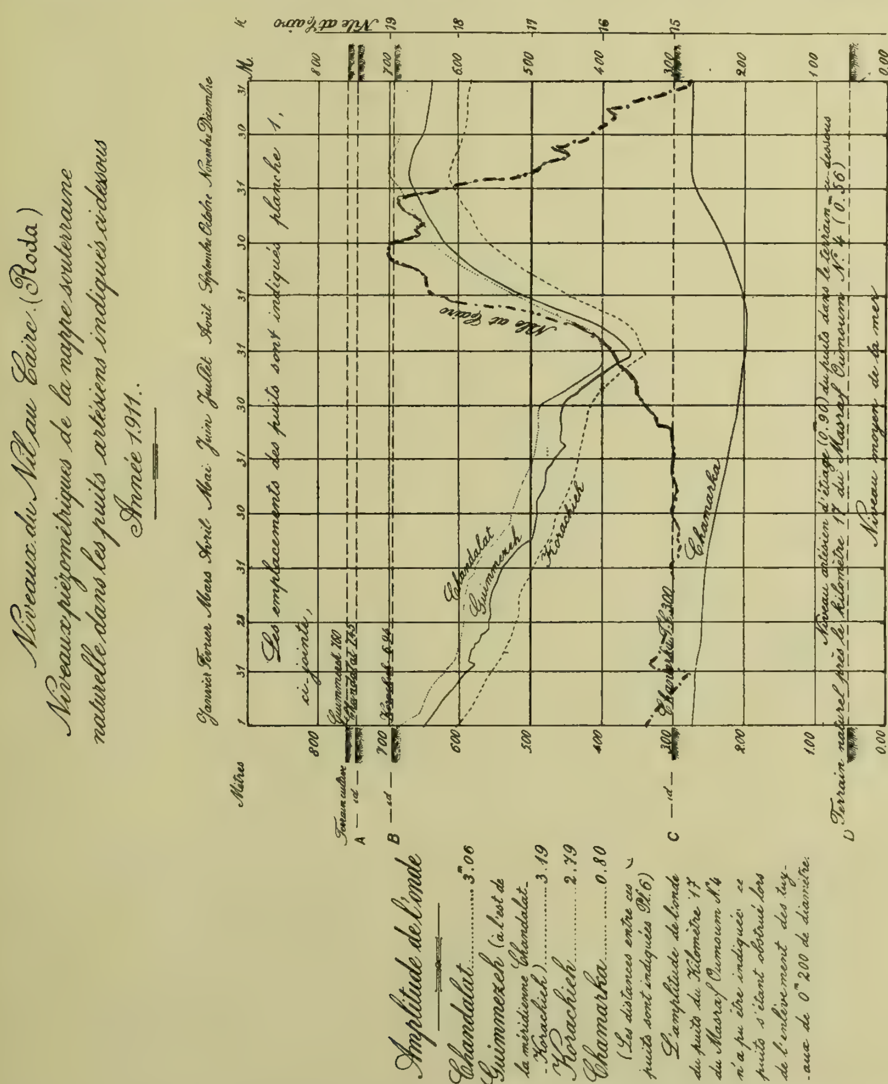


FIG. 8.

In the Alexandria catacombs, the fluctuation in a mean year is 33 centimetres; at Shamarka, removed 50 kilometres from the Mediterranean, the fluctation is 80 centimetres; at Korashia, removed 81 kilometres from the sea, the figure becomes 2·79 metres; and at Shandallat, 9 kilometres further south, it is 3·19 metres. The amount of fluctuation keeps on increasing up to the bifurcation.

To the north of Cairo the velocity of the subsoil water decreases as we go northwards. During the whole period of the flood, the natural subsoil water flows

directly into the sea through the subjacent stratum of sand. During the time of low supply of the Nile, some of the subsoil water flows back into the two branches of the river and aids their low supply, while the rest enters the sea.

The natural subsoil water flows into the sea some distance from the coast line; this distance is evidently smaller on the side of Alexandria than of Port Said, owing to the fact that the sea current has carried the alluvium eastwards and deposited more of it there. The beds of the lakes bordering the Mediterranean are,

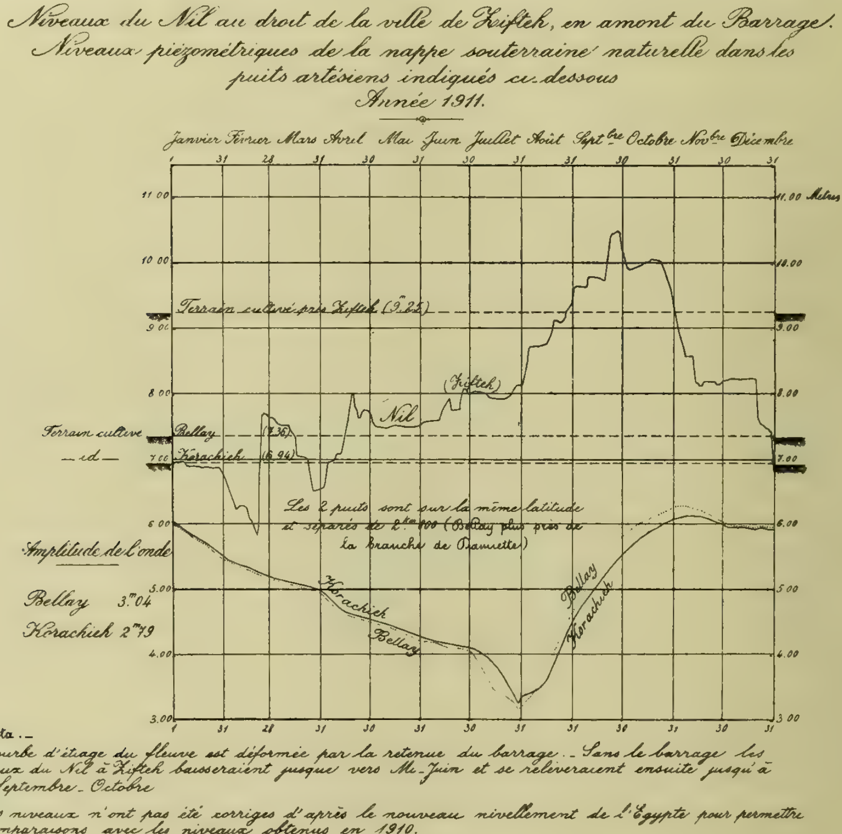



FIG. 9.

generally speaking, below sea-level. The lands to the immediate south of the lakes for a distance of 30 kilometres in places are about sea-level and sometimes lower than sea-level. One might deduce from this that deep borings in the lakes or just to the south of them would give true artesian supplies. Deep bores made by me in 1911, in the neighbourhood of Lake Borollos, have confirmed this hypothesis. This has also been confirmed by a 56-metre deep boring at Port Said, by the very deep boring at Tel Balamûn, and in the Alexandrian catacombs. In the catacombs the water-level in the low galleries is always above mean sea-level which is close at hand, and observations have shown that this level is related to the level of the Nile and is independent of the Mahmudia Canal and Lake Mareotis. The subsoil water-level in the catacombs in February, when it is

at its highest, is about 2·30 metres above the floor of the lower galleries in a year of mean flood. One may conclude therefore that these galleries have sunk 2·30 metres since Roman times, for the subsoil water-level cannot have varied much from what it was then, when we take count of the proximity of the sea and the natural assumption that the floors were just above subsoil water-level when they were made. The very moderate depths of Lakes Menzala, Borollos, and Edku would seem to prove that the settlement in these regions has been less than at Alexandria (unless indeed their beds have been raised a metre or so by the deposits from the flood waters traversing them during the last thirteen hundred years of basin irrigation in the Delta).

Speaking generally, the natural subsoil water in Lower Egypt becomes more and more salted as one advances northwards. It would not have been possible to

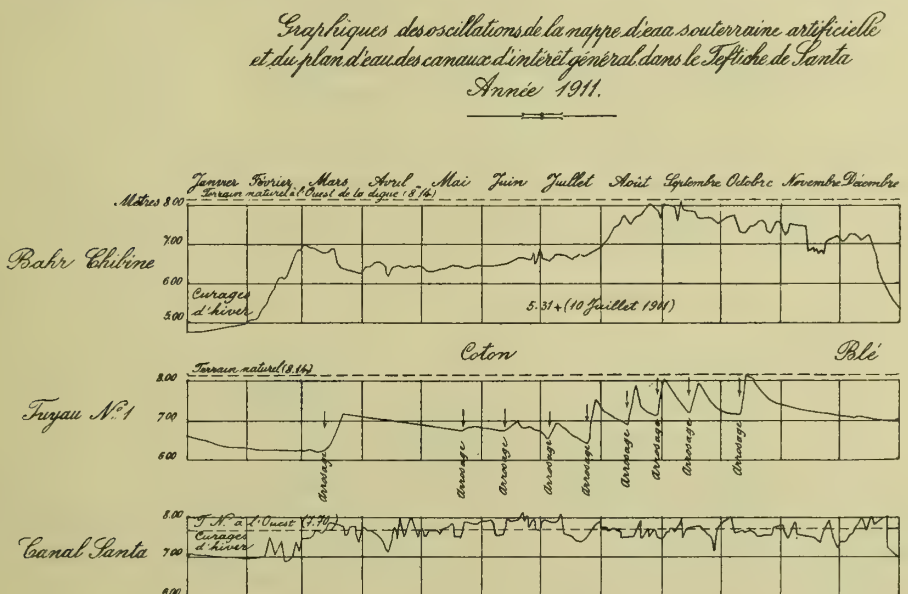



FIG. 10.

reclaim and cultivate the low lands bordering the lakes nor the beds of the lakes themselves, if the soil under them had been as permeable in a vertical direction as most of the lands in the centre and south of the Delta. In the northern parts of the Delta there exist very compact and impermeable strata of stiff clay above the stratum of sand and gravel carrying the subsoil water; and it is only when one has penetrated these compact strata and reached the sand that one meets the natural subsoil water, which rises in the pipe above ground-level. There is therefore nothing to fear from this salted subsoil water in the proximity of the sea and the lakes.

As the ancient basins of Upper and Middle Egypt are converted to perennial irrigation one after the other, the Nile flood reaches Lower Egypt earlier and earlier, and attains a higher level. The natural subsoil level follows the regime of the Nile, and it too rises earlier than it used to, and moreover attains a greater height.

ARTIFICIAL SUBSOIL WATER.—Pipes sunk to a moderate depth of from 1·50 to 3·00 metres in the ground allow us to study the movements of artificial subsoil water. In the case of soils which are easily permeable in a vertical direction, the

surface level of the artificial and natural subsoil waters is one and the same. In this case, surface irrigation cannot raise the subsoil water-level very appreciably. In the impermeable subsoil of the northern part of Lower Egypt, the natural subsoil water is at a low level and totally different from the artificial subsoil water which is near the surface. If the impermeable strata of these regions are bored through, the natural subsoil water rises to a higher level than the artificial subsoil water and generally rises above ground-level.

In the centre and south of the Delta, few localities indeed have all the strata from the top to bottom quite impermeable. Certain are nearly impermeable, but others are very porous in a vertical direction. In soils with little vertical permeability, the action of irrigation water is disclosed by the rapid rise of the artificial subsoil water which follows each irrigation. It very often happens that soils, impermeable or nearly so in a vertical direction, are permeable along porous strata cut through by canals. If the canals are maintained at a low level, these porous strata act almost like drains for the lands in which they exist. But if the canals are maintained at a high level in order to ensure flush irrigation throughout the year, infiltrations become serious and occasionally the lands become sterile. The subsoil water courses along these porous strata and comes to the surface when they come to the surface; and we see, in consequence, sometimes, fields near the canals in prime condition and those farther away covered with alkali."

The following notes were published by the Survey Department in 1912:—

### The Slope of the Water-Table in the Neighbourhood of Irrigation Channels.

"There are six lines of Survey Department tube-wells, at approximately equidistant localities in the provinces of Menufîa and Gharbîa. Each line includes about fifty tube-wells which are usually spaced out at 100-metre intervals, though near canals this spacing is sometimes greatly reduced. The lines intersect irrigating channels nearly at right angles, and all the wells have been measured regularly once a week for the last two years.

The accompanying diagram represents a cross-section near Mehalla el Kubra in central Gharbîa, along a part of the Rahebein line of tube-wells. This line crosses a public drain, the Mohît No. 1, and that great arterial canal, the Bahr Shibîn.

The water-levels represented on the curve are the means of nine observations, four being made during each of the specified months, January, July, and November in the year 1910, and five during the same months in the year 1911. The curves, therefore, represent nearly average soil-water conditions during the periods of general winter closure, of general scarcity of water and of flood.

It may be remarked that the alluvium along this line of wells appears to be unusually sandy, and therefore unusually porous.

PART OF THE RAHEBEIN LINE OF TUBE-WELLS (NEAR MAHALLA EL KUBRA, CENTRAL GHARBIA).

Diagram showing the mean position of the water-table during the months of January 1910 and 1911, July 1910 and 1911, and November 1910 and 1911.

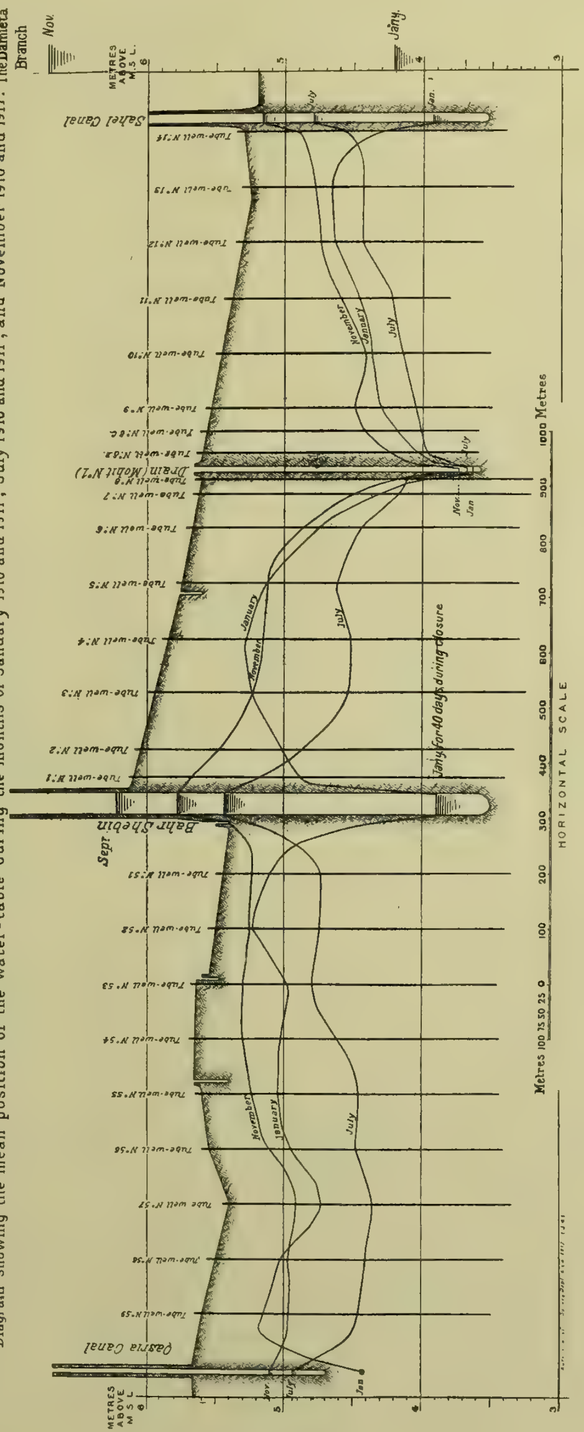



FIG. 11.

| Date. | Rahebein Upstream R.L. in metres. | | Damietta Branch R.L. at Samanud in metres. | |
|---|---|---|---|---|
| | 1910. | 1911. | 1910. | 1911. |
| January 15 | 4·10 | 4·60 | 4·20 | 4·00 |
| February 14 | 4·75 | 5·55 | 3·30 | 2·80 |
| March 15 | 5·20 | 5·50 | 2·70 | 2·60 |
| April 15 | 5·54 | 4·90 | 2·70 | 2·60 |
| May 15 | 5·50 | 5·10 | 2·70 | 2·60 |
| June 15 | 5·15 | 5·00 | 2·50 | 2·40 |
| July 15 | 5·40 | 5·35 | 2·40 | 2·40 |
| August 15 | 6·07 | 5·82 | 4·75 | 4·60 |
| September 15 | 6·12 | 6·25 | 7·80 | 7·15 |
| October 15 | 6·00 | 6·05 | 7·90 | 7·10 |
| November 15 | 6·05 | 5·55 | 6·90 | 6·50 |
| December 15 | 5·35 | 5·70 | 4·65 | 3·40 |

### The Level of the Subsoil Water in Giza Province before and after the Introduction of Perennial Irrigation.

The level of water standing in a number of disused sakia-pits and tube-wells between Giza and the Pyramids has been observed by Mr Ferrar since 1906, with the exception of the year 1907. The curves given in figs. 4 and 5 show the level of the water in two pits, one of them being in the land which was brought under perennial irrigation in the summer of 1910, whilst the other, given for purposes of comparison, is to the west of the Mohit drain in the land still under basin irrigation.

It will be seen that whereas under flood irrigation the water-level in pit No. 1 fell in the summer to as low as 5 metres below soil-level, it is now never more than 3 metres below the soil and is fairly constant throughout the spring and summer. No. 3 shows no essential difference between the curves of 1906, 1908, and 1909 and those of 1910 and 1911, though there is some evidence from other wells that perennial irrigation may produce a small effect on wells in neighbouring basin-land."

We note in passing that the rise of ground water at Giza, owing to perennial irrigation, would have been much greater had not the effect of the water held up at the Delta Barrage been felt here in 1906 during the time of basin irrigation.

We quote the following summary of a study of the effect of water on the cultivation of cotton by the Survey and Agricultural Departments in 1911, and published by the Survey Department as their paper No. 24 of 1912.

"The report contains an account of:—

(*a*) An experiment known as the Gemmeiza Strip Experiment, to determine the relation between the height of the water-table or level of the subsoil water and the yield of cotton.

(*b*) A comparison of the height of the water-table and the yield of cotton at a number of places in the Delta during 1910 and 1911.

(*c*) A weir discharge experiment to determine the quantity of water actually led on to a cotton field.

*The Gemmeiza Strip Experiment.*—In this, cotton was grown on land under which there was a sloping water-table. The experimental area was divided into a number of plots, and the level of the water-surface underlying each of these was determined by means of bore-holes, and the yield of cotton from each by weighing.

Further, a row of cotton in each plot was isolated for particular observation, and the rate of flowering, boll-shedding, etc., was measured during the season.

CURVE SHOWING INCREASE OF YIELD WITH INCREASE OF DEPTH TO WATER-TABLE

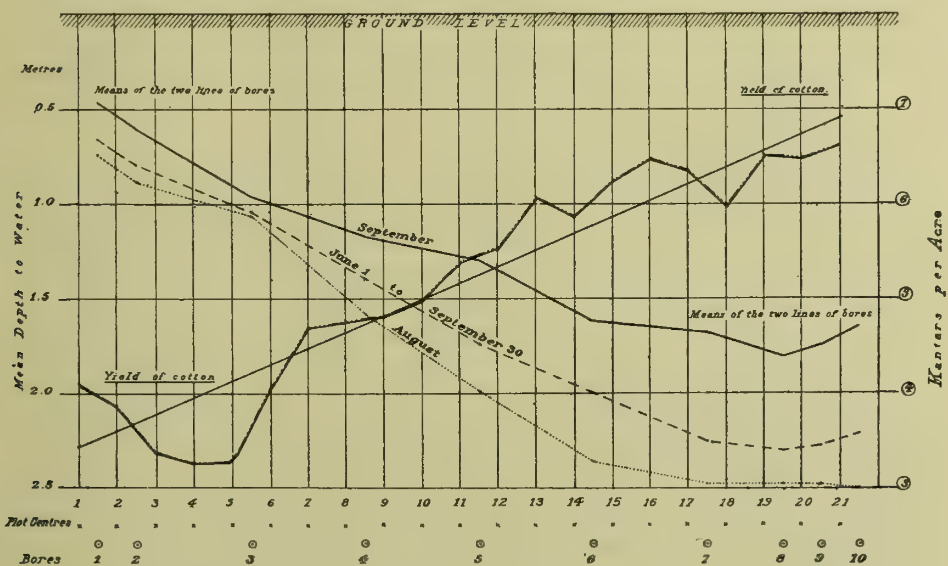



FIG. 12.

From this experiment, it is concluded:—

(i.) That there is a steady increase in the yield of cotton as the thickness of the layer of soil above the water-table increases.

In this particular case, down to a depth of about 2 metres below the surface of the ground, a metre decrease in the height of the water-table produced an increase of about 1·9 kantar of seed-cotton per acre;* and the yield of those plots where the water-table was on the average below 2 metres from the ground surface, was one and three-quarter times the yield of those plots where the water was nearer the surface than 1 metre.

(ii.) That, as the thickness of the layer of soil above the water-table increases, all the factors which determine the magnitude of the crop increase: such as the number of flowers produced, the percentage of flowers which become ripe bolls, and the lint-weight per boll. The height of the plants, the weight of a single seed,

* 1 kantar of seed-cotton = 315 rotls = 142 kilograms = 312 lbs. 1 acre = 4200 square metres = 1·04 English acre.

and the number of seeds per boll also increased; so that we may say that the general productiveness of the cotton plants increased as the height of the water-table decreased.

(iii.) That the rise of the water-table at the end of the summer caused a diminution of the crop. In this case the loss was not so great as that due to a general high level of the water-table. The effect of the rise, however, depends upon the time at which it occurs—the earlier the rise the greater the damage—and the rise in 1910 began rather late.

*The Comparison of the Height of the Water-Table and the Yield of Cotton at a Number of Places in the Delta.*—In these observations the height of the water-table was observed along five lines of tube-wells by Egyptian observers, who also gave estimates of the crop round each well, based either on their observations or on figures supplied by the owners of the fields. In all there were 161 separate returns of water-level and yield during 1910 and 1911. The results confirmed those of the Gemmeiza experiment. They show that at first the yield of cotton increases as the depth to the water-table increases; but that after a certain depth, which varies with the locality, the yield tends to become constant.

There is not sufficient evidence to speak with certainty about the depth of the water-table at which a constant yield is obtained; but so far as the evidence goes, the conclusion is that in three out of the five localities it would be an advantage so to drain the land as to keep the water-table below 2 metres from the surface of the ground. In one locality a stationary yield seems to be reached when the water-table is 1 metre below the surface. From this it would seem that the level of the water-table which is most favourable for the cotton crop varies with the locality.

The results of these comparisons are most striking when we consider the diversity of the causes influencing the yield of cotton. The fields were in different localities, and consequently there were considerable differences: in the soil, in the agricultural operations, and in all the factors influencing plant-growth. From the close connection between the yield of cotton and the height of the water-table found in these cases, it seems probable that the latter is one of the most important of the causes which determine the magnitude of the cotton crop.

*The Mit Maimûn Experiment.*—In this experiment the quantity of water flowing on to the land at the various waterings of the cotton crop was measured.

Supposing the water to have been distributed evenly over the experimental area, the average thickness of the layer put on at a watering was 8·1 centimetres, or 340 cubic metres per feddan. This is supposed to be rather less than the average amount used in agricultural practice. The rise of water in bore-holes situated in the experimental plot was usually about seven times the thickness of the layer applied to the land."

13. **Areas of Land under Basins and perennially irrigated.**—The total cultivable area of Egypt may be taken as 6,663,000 acres, of which 1,312,000 may be taken as uncultivated and 5,351,000 as cultivated.

Upper Egypt has 2,251,000 acres under cultivation, and Lower Egypt 3,100,000. The whole of Lower Egypt is said to be perennially irrigated, while in Upper Egypt 1,287,000 acres are under basin irrigation and 964,000 acres under perennial irrigation.

The area under basin irrigation is therefore 1,287,000 acres and under perennial irrigation 4,064,000, with 1,312,000 acres still to be cultivated. The following table gives details of these figures :—

TABLE 50A.—AREAS OF PROVINCES IN ACRES.

| Province. | Uncultivated. | Cultivated. | | | Total Area. |
|---|---|---|---|---|---|
| | | Basin. | Perennial. | Total. | |
| *Upper Egypt—* | | | | | |
| Aswan . . | ... | 87,000 | ... | 87,000 | |
| Kena . . . | ... | 353,000 | ... | 353,000 | |
| Girga . . . | ... | 313,000 | ... | 313,000 | |
| Assiut . . | ... | 348,000 | 62,000 | 410,000 | |
| Minia . . . | ... | 96,000 | 287,000 | 383,000 | |
| Beni Suef . . | ... | 38,000 | 186,000 | 224,000 | |
| Fayum . . | ... | ... | 304,000 | 304,000 | |
| Giza . . . | ... | 52,000 | 125,000 | 177,000 | |
| Total, Upper Egypt. | 122,000 | 1,287,000 | 964,000 | 2,251,000 | 2,373,000 |
| *Lower Egpyt—* | | | | | |
| Kaliubia . . | ... | ... | 181,000 | 181,000 | |
| Sharkia . . | ... | ... | 535,000 | 535,000 | |
| Dakahlia . . | ... | ... | 495,000 | 495,000 | |
| Menufia . . | ... | ... | 346,000 | 346,000 | |
| Gharbia . . | ... | ... | 954,000 | 954,000 | |
| Behera . . | ... | ... | 587,000 | 587,000 | |
| Governorates . | ... | ... | 2,000 | 2,000 | |
| Total, Lower Egypt. | 1,190,000 | ... | 3,100,000 | 3,100,000 | 4,290,000 |
| Egypt . . . | 1,312,000 | 1,287,000 | 4,064,000 | 5,351,000 | 6,663,000 |

Independent of the land irrigated directly by free flow from the canals, the basin and perennial irrigation is supplemented by the following machines for lift irrigation :—

TABLE 50B.—PUMPS AND SAKIAS IN EGYPT.

| Description. | Basin Irrigation. | Perennial Irrigation. | Total. |
|---|---|---|---|
| Pumps on the Nile, No. . . . . | 104 | 416 | 520 |
| ,, ,, , H.P. . . . . | 4,247 | 5,612 | 9,859 |
| Pumps on canals and drains, No. . | 20 | 3,392 | 3,412 |
| ,, ,, ,, , H.P. . | 385 | 34,820 | 35,205 |
| Pumps in wells in fields, No. . . | 740 | 2,291 | 3,031 |
| ,, ,, , I.H.P. . . . . | 11,740 | 23,010 | 34,750 |
| Sakias on the Nile . . . . . | 3,778 | 759 | 4,537 |
| ,, on canals and drains . . | 1,250 | 60,077 | 61,327 |
| ,, in the fields . . . . . | 40,631 | 5,255 | 45,886 |

In addition to the above, shadufs (or buckets and levers worked by men) are employed very largely indeed in the southern provinces, and moderately further north.

14. **Principal Crops, Trees, and Animals.**—The principal crops grown in Egypt are the following:—

*Winter Season.*

| | |
|---|---|
| Clover about | 1,400,000 acres. |
| Wheat ,, | 1,250,000 ,, |
| Beans ,, | 550,000 ,, |
| Barley ,, | 400,000 ,, |

*Summer Season.*

| | |
|---|---|
| Cotton | 1,650,000 acres. |
| Millets and maize | 170,000 ,, |
| Sugar-cane | 50,000 ,, |
| Rice | 240,000 ,, |
| Various | 73,000 ,, |

*Flood Season.*

| | |
|---|---|
| Millets and maize | 1,700,000 acres. |
| Rice | 50,000 ,, |
| Gardens and orchards cover | 30,000 ,, |

The following table gives full details of these figures by basins and perennial tracts and by the Inspectorates of Irrigation of Upper and Lower Egypt. The figures have been taken from those published by the Finance Ministry, but the winter crops in the basins seem to us below the actual areas.

Chapter XIV. gives the different crops grown in Egypt in great detail for the agricultural year 1911–12.

The most valuable tree in the country is the date palm, of which there are 6,000,000 bearing fruit. Of these 4,200,000 are in Upper Egypt and 1,800,000 in Lower.

[Table

TABLE 51.—BASIN AND PERENNIAL TRACT CROPS IN THOUSANDS OF ACRES.

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name of Crop. | Total Basin Irrigation in Egypt. | Perennial Irrigation. | | | | | | | | | Total Perennial Irrigation in Egypt. | Total for Egypt. | Remarks. |
| | | Ibrahimia Canal, | | | | Irrigation by Giza Pumps. | Total, Upper Egypt. | Total, Lower Egypt. | Inspectorate General, Upper Egypt. | Inspectorate General Lower Egypt. | | | |
| | | Fayum. | in Upper Egypt.* | in Giza. | Total. | | | | | | | | |
| *Winter.* | | | | | | | | | | | | | |
| Wheat | 355 | 96 | 118 | 24 | 238 | 12 | 250 | 656 | 214 | 692 | 906 | 1261 | |
| Beans | 248 | 58 | 148 | 6 | 212 | 3 | 215 | 97 | 206 | 106 | 312 | 560 | |
| Barley | 141 | 26 | 14 | 5 | 45 | 2 | 47 | 201 | 40 | 208 | 248 | 389 | |
| Clover, etc. | 364 | 103 | 120 | 25 | 248 | 13 | 261 | 932 | 223 | 970 | 1193 | 1557 | |
| Total, winter | 1108 | 283 | 400 | 60 | 743 | 30 | 773 | 1886 | 683 | 1976 | 2659 | 3767 | |
| *Summer.* | | | | | | | | | | | | | |
| Cotton | 11 | 81 | 196 | 13 | 290 | 6 | 296 | 1335 | 277 | 1354 | 1631 | 1642 | Columns 5 and 7, though in Upper Egypt, are in the Inspectorate General of Lower Egypt. |
| Millets and maize | 97 | ... | 30 | 7 | 37 | 3 | 40 | 33 | 30 | 43 | 73 | 170 | |
| Sugar-cane | 35 | 1 | 7 | ... | 8 | 1 | 9 | 5 | 8 | 6 | 14 | 49 | |
| Rice | ... | ... | ... | ... | ... | ... | ... | 233 | ... | 233 | 233 | 233 | |
| Other crops | 8 | 9 | 8 | 5 | 22 | 2 | 24 | 54 | 17 | 61 | 78 | 86 | |
| Total, summer | 151 | 91 | 241 | 25 | 357 | 12 | 369 | 1660 | 332 | 1697 | 2029 | 2180 | |
| *Flood.* | | | | | | | | | | | | | |
| Millets and maize | 97 | 156 | 247 | 30 | 433 | 15 | 448 | 1131 | 403 | 1176 | 1579 | 1676 | |
| Rice | ... | 15 | ... | ... | 15 | ... | 15 | 39 | 15 | 39 | 54 | 54 | |
| Vegetables | 1 | 4 | 1 | ... | 5 | ... | 5 | 9 | 5 | 9 | 14 | 15 | |
| Total, flood | 98 | 175 | 248 | 30 | 453 | 15 | 468 | 1179 | 423 | 1224 | 1647 | 1745 | |
| Gardens | 10 | 4 | 2 | 1 | 7 | ... | 7 | 15 | 6 | 16 | 22 | 32 | |
| Total for the year | 1367 | 553 | 891 | 116 | 1560 | 57 | 1617 | 4740 | 1444 | 4913 | 6357 | 7724 | |

The two following tables give the statistics of the cotton crop from 1878 to 1911. It will be noted how greatly the price has varied. In 1893 a 5,000,000-kantar crop realised £9,000,000, while the same crop in 1909 realised £24,000,000. Since 1884 the cotton crop has more than doubled. Details of this crop will be found in CHAPTER VII. The next table gives statistics of the sugar-cane crop. During recent years the price of cotton has risen so considerably that the cultivation of sugar-cane has diminished. In the southern provinces, however, sugar-cane is gaining everywhere on cotton.

TABLE 52.—COTTON STATISTICS.

| Year. | Crop in kantars. | Price per kantar. | Value of Crop. |
|---|---|---|---|
| 1878 | 1,700,000 | | |
| 1879 | 2,700,000 | | |
| 1880 | 2,500,000 | | |
| 1881 | 3,100,000 | £ | £ |
| 1882 | 2,500,000 | 3·2 | 8,000,000 |
| 1883 | 2,600,000 | 3·2 | 8,300,000 |
| 1884 | 3,600,000 | 3·0 | 10,800,000 |
| 1885 | 2,790,000 | 2·7 | 7,500,000 |
| 1886 | 2,870,000 | 2·56 | 7,400,000 |
| 1887 | 3,000,000 | 2·48 | 7,400,000 |
| 1888 | 2,730,000 | 2·73 | 7,400,000 |
| 1889 | 3,230,000 | 2·67 | 8,600,000 |
| 1890 | 4,160,000 | 2·27 | 9,400,000 |
| 1891 | 4,770,000 | 1·78 | 8,500,000 |
| 1892 | 5,220,000 | 1·87 | 9,800,000 |
| 1893 | 5,030,000 | 1·75 | 8,800,000 |
| 1894 | 4,620,000 | 1·92 | 8,900,000 |
| 1895 | 5,260,000 | 2·25 | 11,800,000 |
| 1896 | 5,880,000 | 1·90 | 11,200,000 |
| 1897 | 6,540,000 | 1·59 | 10,400,000 |
| 1898 | 5,590,000 | 1·83 | 10,200,000 |
| 1899 | 6,510,000 | 2·48 | 16,100,000 |
| 1900 | 5,440,000 | 2·38 | 12,900,000 |
| 1901 | 6,370,000 | 2·22 | 14,100,000 |
| 1902 | 5,840,000 | 3·19 | 18,600,000 |
| 1903 | 6,510,000 | 3·14 | 20,400,000 |
| 1904 | 6,310,000 | 2·73 | 17,200,000 |
| 1905 | 5,960,000 | 3·49 | 20,800,000 |
| 1906 | 6,950,000 | 3·82 | 26,600,000 |
| 1907 | 7,230,000 | 3·12 | 22,600,000 |
| 1908 | 6,750,000 | 3·03 | 20,500,000 |
| 1909 | 5,000,000 | 4·78 | 23,900,000 |
| 1910 | 7,570,000 | 3·72 | 28,200,000 |
| 1911 | 7,420,000 | 3·44 | 25,500,000 |
| 1912 | 7,500,000 (est.) | | |

Since 1886 the figures have been kindly supplied by the Alexandria Cotton Association.

The following table of sugar-cane statistics has been kindly supplied by M. Naus, managing director of the Société générale des Sucreries et de la Raffinerie d'Egypte. M. Naus states:—

"It is somewhat difficult to produce true statistics about the sugar-cane and sugar production since 1881. I send you the best approximate figures I can find.

"In addition to these surfaces you may count about 14,000 or 15,000 acres yearly sold for direct cane consumption by the natives and for preparing treacle.

"The sugar production per acre seems very low, but it is the average, and many cultivators treat their plantations very badly.

TABLE 53.—SUGAR STATISTICS.

| Year. | Area of Sugar-cane planted in Upper Egypt in acres. | Total Production of Cane in kantars per acre. | Price per Kantar in Piastres Tarif. | Kantars of Sugar produced in kantars per acre. |
|---|---|---|---|---|
| 1881–82 | 23,094 | About 300 to 350 kantars per acre. | About $2\frac{3}{4}$ per kantar. | Variable between 30 and 33 kantars. |
| 1882–83 | 14,477 | | | |
| 1883–84 | 26,315 | | | |
| 1884–85 | 31,454 | | | |
| 1885–86 | 35,519 | | | |
| 1886–87 | 34,078 | | | |
| 1887–88 | 35,481 | | | |
| 1888–89 | 28,989 | | | |
| 1889–90 | 27,092 | | | |
| 1890–91 | 41,841 | | | |
| 1891–92 | 48,494 | | | |
| 1892–93 | 44,318 | | | |
| 1893–94 | 52,598 | | | |
| 1894–95 | 52,231 | | | |
| 1895–96 | 57,892 | | | |
| 1896–97 | 51,598 | | | |
| 1897–98 | 56,375 | | | |
| 1898–99 | 63,844 | | | |
| 1899–00 | 69,591 | | | |
| 1900–01 | 65,125 | | | |
| 1901–02 | 61,886 | About 350 to 400 kantars per acre. | 3 | Variable between 32 and 38 kantars. |
| 1902–03 | 25,894 | | | |
| 1903–04 | 41,139 | | | |
| 1904–05 | 28,889 | | | |
| 1905–06 | 41,210 | | $3\frac{1}{4}$ | |
| 1906–07 | 26,546 | | | |
| 1907–08 | 16,273 | | | |
| 1908–09 | 22,200 | | | |
| 1909–10 | 35,256 | | | |
| 1910–11 | 31,476 | | $3\frac{1}{2}$ | |
| 1911–12 | 35,017 | | | |
| 1912–13 | 42,645 | | | |

"In our own cultivation at Naga Hammadi we obtain on 3500 acres about 850 kantars per acre in the first year's cultivation and 700 kantars in the second year; with a sugar output of 10 per cent. This is nearly double the natives' average."

The principal trees found in the country are sant (*Acacia arabica*), which flourishes wherever it can find water; the lebbek (*Albizzia Lebbek*), much used for shading roads; the sycamore (*Ficus sycamorus*); tamarisk, willow, poplar, eucalyptus, and bamboo. Many other ornamental and timber trees have been introduced and thrive well.

The fruit trees include first and foremost the date palm (*Phœnix dactylifera*), some thirty varieties of which are recognised; the mulberry, vine, orange tree, fig tree, apricot, lemon tree, pomegranate, mango and custard apple. Other fruits are sweet melons, water melons, bananas, and prickly pears.

Other shrubs of some economic importance are roses used for distilling scents, and henna used for dye.

The chief vegetables are—onions, radishes, tomatoes, cabbage, asparagus, turnips, carrots, lettuces, parsley, beetroot, cress, cucumbers, peas, beans, and potatoes.

The principal animals are domesticated, and the chief quadrupeds are the camel, the buffalo, the ox, the ass (indigenous), the horse, the sheep, the goat, and rabbit. Dogs and cats abound in every village. The cat was sacred in ancient Egypt, and even to-day people are afraid to kill them.

The annual census of the Veterinary Service of the Department of Public Health, taken in August or September, gives the following figures (in thousands):—

| | 1903. | 1904. | 1905. | 1906. | 1907. | 1908. | 1909. | 1910. |
|---|---|---|---|---|---|---|---|---|
| Buffaloes . . . | 718 | 646 | 708 | 775 | 761 | 751 | 728 | 675 |
| Other cattle . . | 960 | 605 | 655 | 733 | 779 | 738 | 725 | 672 |

1903 was a year of cattle plague, which decimated the agricultural animals of Egypt.

Of wild animals the commonest are the fox, the jackal, and the gazelle. The ibex and hares are rare, and hyenas are occasionally met with.

15. **Land Proprietors.**—We give from pages 20 and 21 of the second edition the following table of the land possessed by different classes of landowners in 1897. No such table has been prepared since. Since 1897 the Daira Sania Estates have been sold.

| Class of Proprietor, 1897. | Acres, Upper Egypt. | Acres, Lower Egypt. | Acres, Egypt. | Percentage. |
|---|---|---|---|---|
| State Domains | 47,399 | 192,910 | 240,309 | 4·0 |
| State Daira | 306,955 | 31,581 | 338,536 | 6·0 |
| Religious bodies | 16,622 | 56,638 | 73,260 | 1·0 |
| Companies, Foreigners, etc. | 64,645 | 519,537 | 584,182 | 10·0 |
| Non-resident Egyptians | 394,808 | 982,558 | 1,377,366 | 24·0 |
| Resident Egyptians and Fellahin | 1,488,905 | 1,654,603 | 3,143,508 | 55·0 |
| Total | 2,319,334 | 3,437,827 | 5,757,161 | 100·0 |

We extract from the *Annuaire Statistique de l'Egypte* for 1911 the two following tables giving information about the sizes of holdings in Egypt. There are 1,392,000 landowners in Egypt owning 5,464,000 acres, with a mean holding of 3·9 acres. The number of owners of less than 5 acres of land each is 1,247,000, holding 1,370,000 acres, with a mean holding of 1·1 acre. The number of owners of over 50 acres apiece is 12,410, holding 2,460,000 acres, with a mean holding of 200 acres:—

TABLE 54.—NUMBER OF LANDOWNERS AND THEIR HOLDINGS.

| Proprietors. | Number of Proprietors. | Area held in acres. | Mean Holding in acres. |
|---|---|---|---|
| 1898. | | | |
| Egyptians | 824,800 | 4,457,000 | 5·4 |
| Foreigners | 6,500 | 565,000 | 85·0 |
| Total | 831,300 | 5,022,000 | 6·0 |
| 1910 | | | |
| Egyptians | 1,384,300 | 4,744,000 | 3·4 |
| Foreigners | 7,600 | 720,000 | 95·0 |
| Total | 1,391,900 | 5,464,000 | 3·9 |

The mass of the land owned by foreigners is land in the extreme north of the Delta, which has been reclaimed by them, though foreigners own many valuable estates in the heart of the country. Since 1899 the number of registered proprietors has been increasing steadily, and the average holding decreasing.

TABLE 55.—HOLDINGS OF LANDOWNERS IN ACRES, 1910.

| Size of Holdings. | Egyptians. | | | Foreigners. | | | Total. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Number of Proprietors. | Area held in acres. | Mean Holding in acres. | Number of Proprietors. | Area held in acres. | Acres per Holding. | Number of Proprietors. | Area held in acres. | Acres per Holding |
| Under 5 acres . | 1,243,200 | 1,362,900 | 1·1 | 3900 | 6,700 | 1·7 | 1,247,100 | 1,369,600 | 1·1 |
| 5–10 acres . . | 75,400 | 524,600 | 7·0 | 750 | 5,600 | 7·5 | 76,150 | 530,200 | 7·0 |
| 10–20 ,, . . | 36,000 | 497,500 | 13·8 | 650 | 9,500 | 14·6 | 36,700 | 507,000 | 13·8 |
| 20–30 ,, . . | 10,900 | 266,500 | 24·4 | 320 | 8,000 | 24·7 | 11,200 | 274,400 | 24·4 |
| 30–50 ,, . . | 8,020 | 309,400 | 38·5 | 370 | 14,500 | 39·6 | 8,390 | 323,900 | 38·6 |
| Above 50 acres . | 10,850 | 1,782,700 | 164·3 | 1560 | 675,900 | 433·0 | 12,410 | 2,458,600 | 198·0 |

16. **Population.**—The population of Egypt is increasing rapidly. All the districts, with the insignificant exceptions of Siwa and Kosseir, share in this increase, which is exhibited in the following table from the Census of 1907:—

Table 56.—Population.

| | 1897. | 1907. | Increase. | Increase per cent. |
|---|---|---|---|---|
| Governorates | 971,675 | 1,110,120 | 138,445 | 14·2 |
| Behera | 656,419 | 830,015 | 173,596 | 26·4 |
| Gharbia | 1,297,656 | 1,484,814 | 187,158 | 14·4 |
| Menufia | 864,206 | 971,016 | 106,810 | 12·3 |
| Dakahlia | 780,480 | 912,428 | 131,948 | 16·9 |
| Sharkia | 748,872 | 886,346 | 137,374 | 18·3 |
| Kaliubia | 371,602 | 434,575 | 62,973 | 17·0 |
| Lower Egypt | 5,691,010 | 6,629,314 | 938,304 | 16·5 |
| Giza | 401,234 | 460,080 | 58,846 | 14·7 |
| Beni Suef | 312,115 | 372,412 | 60,297 | 19·3 |
| Fayum | 371,006 | 441,583 | 70,577 | 19·0 |
| Minia | 550,971 | 663,144 | 112,173 | 20·4 |
| Assiut | 782,720 | 907,435 | 124,715 | 15·9 |
| Girga | 688,011 | 797,940 | 109,929 | 16·0 |
| Kena | 711,457 | 780,849 | 69,392 | 9·8 |
| Aswan | 208,704 | 234,602 | 25,898 | 12·4 |
| Upper Egypt | 4,026,218 | 4,658,045 | 631,827 | 15·7 |
| Total, Egypt | 9,717,228 | 11,287,359 | 1,570,131 | 16·2 |

The rate of increase is greatest where irrigation projects have been most active during the ten-years period, viz. in Behera, Sharkia, Minia, Beni Suef, and the Fayum. It will be found* that even when allowance is made to the full for immigration from other districts, the rate of increase has been greatest in Behera, where the greatest extension of irrigation has taken place. The mean increase in cultivation for the five mudirias with greatest change of population is 20 per cent.; in the next four, 6 per cent., and in the last five, 4 per cent. Cultivation increased 13 per cent. between 1897 and 1907, but population increased 16 per cent. Since the wealth of Egypt lies almost entirely in its agriculture, it is clear that population has increased more rapidly than the cultivation, and had it not been for the great rise in the prices of exported goods (chiefly raw cotton), the fellah would have been worse off in 1907 than ten years previously. Should prices ever return to the low levels of the 'nineties, a disaster would certainly result, unless in the interval loss in price is made up by gain in yield. The density in Upper Egypt, especially in the southern provinces,

* See *Cairo Scientific Journal*, v. p. 178.

where the deserts contain nitrates and the fellahin and resident Egyptians possess great part of the land, is in striking contrast to the scarcity of population in the province of Minia, where the same classes possess less than 40 per cent. of the land, and where the deserts contain no nitrates.

The average area of a plot of land found by the Cadastral Survey was as follows:—

TABLE 57.—AVERAGE HOLDINGS IN ACRES PER OWNER, 1907.

| | | | | | |
|---|---|---|---|---|---|
| Behera | | acres | Giza | 2·4 | acres |
| Gharbia | | ,, | Fayum | 3·3 | ,, |
| Menufia | 1·4 | ,, | Beni Suef | 1·9 | ,, |
| Dakahlia | 3·4 | ,, | Minia | 3·8 | ,, |
| Sharkia | 4·1 | ,, | Assiut | 1·9 | ,, |
| Kaliubia | 2·5 | ,, | Girga | 1·6 | ,, |
| | | | Kena | 2·0 | ,, |
| | | | Aswan | 2·6 | ,, |

TABLE 58.—DENSITY OF POPULATION, 1907.

| Name of Province. | Cultivated Area in acres. | Area of Crops, including Areas cultivated twice. | Density per acre. |
|---|---|---|---|
| Suez Canal Governorate | 6,000 | 10,000* | ... |
| Behera | 636,000 | 873,000 | ·95 |
| Gharbia | 970,000 | 1,362,000 | 1·09 |
| Menufia | 346,000 | 559,000 | 1·74 |
| Dakalia | 489,000 | 800,000 | 1·14 |
| Sharkia | 539,000 | 827,000 | 1·07 |
| Kaliubia | 181,000 | 285,000 | 1·32 |
| Lower Egypt | 3,167,000 | 4,716,000 | 1·41 |
| Giza | 183,000 | 234,000 | 1·97 |
| Beni Suef | 225,000 | 279,000 | 1·33 |
| Fayum | 307,000 | 565,000 | ·78 |
| Minia | 383,000 | 519,000 | 1·28 |
| Assiut | 412,000 | 491,000 | 1·85 |
| Girga | 313,000 | 367,000 | 2·17 |
| Kena | 345,000 | 417,000 | 1·87 |
| Aswan | 67,000 | 74,000 | 3·19 |
| Upper Egypt | 2,235,000 | 2,946,000 | 1·58 |
| Egypt | 5,402,000 | 7,662,000 | 1·47 |

* Acres in nearest thousand.

17. **Railways, Roads, and Navigation.**—The railways of Egypt are either (*a*) State owned or (*b*) owned by public companies. The former comprise the main railway network of the country, and consist of standard gauge lines, and the narrow gauge lines from Luxor to Aswan, to the Oasis of Kharga, and the auxiliary lines. The private railroads are those owned by the Delta Light Railway Company, which include the Helwan line and the Delta network; by the Société Anonyme des Chemins de Fer de la Basse Egypte; and by the Fayum Light Railway Company. The concessions of the three public companies expire in 1972, 1949, and 1972 respectively, when their properties lapse to the State without compensation.

The following summarise the principal data:—

TABLE 59.—STATISTICS OF RAILWAYS IN EGYPT AT THE END OF 1910.

| Proprietor. | Gauge. | Stations. | Length of Lines. | Length in Single Road. | Secondary Branches, etc. | Sidings. | Passengers carried. | Merchandise carried. In tons. |
|---|---|---|---|---|---|---|---|---|
| | m. | | km. | | | | | |
| State (Main lines) . | 1·435 | 260 | 2039 | 2575 | 105 | 698 | 25,727,000 | 3,856,000 |
| „ (Nubian line) . | 1·067 | 17 | 222 | 222 | 2 | 21 | | |
| „ (Oases line) . | 0·75 | ... | 195 | ... | ... | ... | 15,764 | 6,398 |
| „ (Auxiliary lines) | ... | ... | 533 | with sidings | ... | ... | 650,421 | 440,416 |
| Delta Light Railways . | 0·75 | ... | 951 | ... | ... | ... | 6,041,745 | 819,607 |
| „ „ „ . | 1·435 | ... | 40 | ... | ... | ... | 1,092,663 | 295,957 |
| Société Anonyme des Chemins de Fer de la Basse Egypte . | 1·00 | ... | 109 | ... | ... | ... | 1,019,064 | 73,120 |
| Fayum Light Railways | 0·75 | ... | 168 | ... | ... | ... | 708,275 | 115,415 |
| Mariut Railway . | 1·435<br>1·00 | ... | 165<br>65 | ... | ... | ... | 140,690 | |

TABLE 60.—RAILWAY FINANCES.

| Proprietor. | Receipts. Passengers. | Receipts. Goods. | Receipts. Total. | Expenses. Total. | Expenses. Percentage of Receipts. | Receipts per km. | Expense per km. |
|---|---|---|---|---|---|---|---|
| | £1000 | £1000 | £1000 | £1000 | % | £ | £ |
| State Main and State Nubian lines . . . | 1652 | 1709 | 3400 | 1973 | 60·6 | 1453 | 843 |
| „ Auxiliary lines . . | 11 | 22 | 34 | 30 | 91·69 | | |
| „ Oases line . . | 3 | 3 | 6 | 8 | ... | | |
| Delta Light Railways . . | 130 | 70 | 206 | 120 | 58·3 | 217 | 126·5 |
| „ „ (Helwan Branch) | 36 | 15 | 53 | 39 | 73·15 | 1324·5 | 968·8 |
| Société Anonyme des Chemins de Fer de la Basse Egypte . . . | 23 | 11 | 34 | 17 | 49·82 | 310·2 | 154·5 |
| Fayum Light Railways . | 14 | 10 | 25 | 17 | 66·62 | 148 | 98·6 |
| Mariut Railway . . . | 7 | 13 | 20 | ... | ... | 88·3 | |

The principal commodities carried by the State Railways in the year 1910 were:—

| | | | |
|---|---|---|---|
| Animals . . | 601,618 head. | Timber . . | 277,568 tons. |
| Coals . . . | 579,866 tons. | Cotton (ginned) . | 261,841 „ |
| Building Material . | 487,263 „ | Cotton (unginned) | 210,832 „ |
| Cotton Seed . . | 417,301 „ | Oil and Grease . | 117,985 „ |
| Cereals . . | 334,982 „ | Machinery, etc. . | 101,757 „ |

There are 900 kilometres of agricultural roads in Upper Egypt, and just over 2000 kilometres in Lower Egypt, or 2900 kilometres in all. These roads are unmetalled.

The Public Works Department has published a list of all the locks on the navigable canals and waterways of Egypt from which the following notice is taken:—

"Regarding the limiting dimensions of craft plying on the navigable canals extracted from *Official Journal* of 25th April 1906:—

| Description of Vessel. | Maximum Length. | Maximum Width. | Maximum Draught. |
|---|---|---|---|
| | metres. | metres. | metres. |
| Steam or Motor Barges . . . . | 40·00 | 7·0 | 2·0 |
| Cargo Barges . . . . . . | 30·00 | 6·0 | 2·0 |
| Tugs . . . . . . . | 22·00 | 4·5 | 1·7 |
| Country Boats . . . . . | 22·00 | 6·0 | 2·0 |

The dimensions have been fixed as above after examination of the statements showing the dimensions of the craft actually plying on the river and canals submitted by the various navigation companies.

It should, however, be remembered, when placing orders for new barges, that the Rayah Behera, which will probably be made available for through navigation in the early future, will not admit any barge exceeding 35 metres in length. The Rayah Behera, owing to its entire freedom from railway bridges and better depth of water, will afford many facilities for navigation.

It must be understood that it is only the main canals, such as—

The Rayah Menufia,
The Baguria,
The Mahmudia,
The Rayah Tewfiki,
The Mansuria,

which are capable of passing craft of the above dimensions.

Many of the locks on the other navigable canals are too small to accommodate craft of this size, and, during summer, the depth of water in the tail reaches often falls much below 1½ metres.

It must be further understood that even in the main canals, a depth of 2·00 metres can by no means always be depended on, and that during seasons of low supply owners will run the risk of grounding barges and boats if they load them so as to make their draught reach or nearly reach the limiting value of 2·00 metres.

As a general rule, navigation on the Rosetta and Damietta branches of the Nile, in the reaches from the Delta Barrage northwards, may be considered to cease when the gauge readings downstream of the Barrages fall below 13·30 for the Rosetta and 13·60 for the Damietta branch.

The width of navigable openings on the Nile are as follows:—

| | Metres. |
|---|---|
| *Main Nile—* | |
| Aswan Barrage Lock | 80·0 × 9·50 |
| Esna Barrage Lock | 80·0 × 16·0 |
| Naga Hammadi Railway Bridge | 30·2 |
| Assiut Barrage Lock | 80·0 × 16·0 |
| Roda Road Bridge | Two openings of 20·00 each. |
| Cairo Road Bridge | 22·8 |
| Bulak Road Bridge | 26·5 |
| Embaba Railway Bridge | 24·4 |
| *Gezira Branch of Nile at Cairo—* | |
| Upper Bridge | Two openings of 20·00 each. |
| Lower Bridge | ,, ,, ,, ,, ,, |
| *Rosetta Branch—* | |
| Rosetta Barrage Locks | 53·5 × 11·8<br>64·2 × 12·0 |
| Kafr el Zayat Railway Bridge | 24·3 |
| Desûk Railway ,, | 26·0 |

*Damietta Branch—*

| | Metres. |
|---|---|
| Damietta Barrage Locks | 53·5 × 11·8<br>64·2 × 12·0 |
| Barrage Railway Bridge | 28·1 |
| Benha Road Bridge | 18·3 |
| Benha Railway Bridge | 25·5 |
| Zifta | 25·7 |
| Zifta Barrage Lock | 64·5 × 12·0 |
| Mansura Railway Bridge | 24·6 |

The following information is taken from Mr J. Langley's report on the Irrigation of Upper Egypt for 1910.

The following boats and steamers passed through the Assiut Barrage Locks:—

*Going Downstream.*

7590 boats; tonnage, 1,780,000 ardebs.
1340 „ empty.

8930 boats (laden and empty).

49 dahabias (house boats).
233 steamers.

*Going Upstream.*

3770 boats; tonnage, 1,040,000 ardebs.
4860 „ empty.

8630 boats (laden and empty).

47 dahabias.
243 steamers.

The laden boats going up and down stream numbered 11,360, with a tonnage of 2,820,000 ardebs, or the mean tonnage of a boat was 250 ardebs.

An ardeb measures 198 litres or 5·45 bushels.

The following table has been prepared by Mr H. G. Finlayson, Inspector of Works.

Space under Bridges at Commencement and End of Nile Floods.—The statement below shows reduced levels of the River Nile at Roda which allows free passage to certain steamers, underneath certain bridges:—

| Name of Bridge . . . . . | | Abbas Bridge at Giza. | Kasr el Nil. | Boulak. | Embaba. |
|---|---|---|---|---|---|
| Distance from Roda in kilometres . | | 1 km. | 4½ kms. | 5½ kms. | 9½ kms. |
| R.L. Underside of Girder in metres . | | 22·26 | 22·26 | 20·60 | 21·30 |
| Name of Steamer. | Headway required for Steamer. | Roda Gauge Readings at which Steamer will pass. | | | |
| | metres. | metres. | metres. | metres. | metres. |
| Messir | 12·50 | 9·84 | 10·12 | 8·54 | 9·56 |
| Dendera | 10·25 | 12·09 | 12·37 | 10·79 | 11·81 |
| Sahkara | 8·75 | 13·59 | 13·87 | 12·29 | 13·31 |
| Cynthia | 8·75 | 13·59 | 13·87 | 12·29 | 13·31 |
| Daleel | 7·50 | 14·84 | 15·12 | 13·54 | 14·56 |
| Boulac | 6·70 | 15·64 | 15·92 | 14·34 | 15·36 |
| Tanta | 5·75 | 16·59 | 16·87 | 15·29 | 16·31 |
| Kahira | 5·50 | 16·84 | 17·12 | 15·54 | 16·26 |
| Rakeeb | 4·85 | 17·49 | 17·77 | 16·19 | 17·21 |
| Tawaf | 4·85 | 17·49 | 17·77 | 16·19 | 17·21 |
| Bafeek | 4·85 | 17·49 | 17·77 | 16·19 | 17·21 |
| Moeris | 4·75 | 17·59 | 17·87 | 16·29 | 17·31 |
| Launch No. 74 | 3·65 | 18·69 | 18·97 | 17·39 | 18·41 |

*Note.*—The above Roda gauge readings which allow steamers to pass have been obtained by adding to the necessary reduced level of water surface at the bridge the fall between Roda gauge site and the bridge. This fall is considered to be 8 centimetres per kilometre at the beginning and end of the flood in this reach. During the flood the water slope is considerably more.

18. **Imports and Exports.**—The details of foreign trade in 1905 and 1910 were:—

IMPORTS.

| | 1905. £ | 1910. £ |
|---|---|---|
| Animals | 1,179,000 | 1,123,000 |
| Skins, leather, goods, etc. | 392,000 | 462,000 |
| Cereals, vegetables, flour | 2,793,000 | 2,740,000 |
| Provisions and drugs | 934,000 | 945,000 |
| Spirits, liqueurs, etc. | 985,000 | 1,161,000 |
| Rags, paper, and books | 313,000 | 390,000 |
| Wood and coal | 2,679,000 | 2,834,000 |
| Stone, cement, and glass | 489,000 | 618,000 |
| Dyeing materials and colours | 265,000 | 256,000 |
| Chemical products and perfumes | 457,000 | 976,000 |
| Textile goods | 6,053,000 | 6,626,000 |
| Metal and metal goods | 2,837,000 | 2,384,000 |
| Tobacco | 687,000 | 1,155,000 |
| Sundries | 1,500,000 | 1,882,000 |
| Total | 21,564,000 | 23,553,000 |

The principal imports are textile goods, cereals, wood, coal, and metals.

EXPORTS.

| | 1905. £ | 1910. £ |
|---|---|---|
| Animals | 101,000 | 161,000 |
| Skins, leather, goods, etc. | 217,000 | 294,000 |
| Cereals, vegetables, etc. | 2,730,000 | 3,223,000 |
| Sugar, provisions, etc. | 630,000 | 195,000 |
| Liqueurs, spirits, and oils | 18,000 | 25 000 |
| Rags, paper, and books | 14,000 | 24,000 |
| Wood, straw, cane, etc. | 17,000 | 17,000 |
| Dyeing materials and colours | 27,000 | 28,000 |
| Perfumery, etc. | 15,000 | 43,000 |
| Cotton and fibres | 15,962,000 | 24,376,000 |
| Metal goods | 20,000 | 54,000 |
| Sundries | 55,000 | 122,000 |
| Cigarettes | 554,000 | 379,000 |
| Total | 20,360,000 | 28,941,000 |

The principal exports are cotton, cereals, and cigarettes. Sugar has ceased to be an item of much consequence. A glance at the two tables shows the extent to which Egypt depends on cotton for its foreign supplies.

19. **Revenue, Expenditure, and Debt.**—The revenue of Egypt is derived from taxation—direct and indirect—fees and charges for services rendered, rent of the State domain, dividends on investments, profits on State industries, and penal revenue.

For comparison we give the budgetary details for 1905 and 1910, to the nearest £100.*

REVENUE.

| | 1905. £ | 1910. £ |
|---|---|---|
| Direct Taxes— | | |
| Land tax | 4,766,700 | 5,118,900 |
| Date tax | 121,000 | 137,900 |
| House tax | 157,800 | 282,400 |
| | 5,045,500 | 5,539,200 |
| Indirect Taxes— | | |
| Customs | 1,799,100 | 1,904,800 |
| Tobacco | 1,525,500 | 1,591,300 |
| Salt | 177,900 | 3,700 |
| Ports and lighthouses dues | 364,800 | 396,400 |
| Fisheries | 57,200 | 45,300 |
| Navigation dues | 12,600 | 4,000 |
| Stamp duty | 45,900 | 47,800 |
| Miscellaneous | 55,900 | 65,400 |
| | 4,038,800 | 4,058,900 |

* £ (E.), or Egyptian pound = £1, 0s. 6d.

| | 1905. | 1910. |
|---|---|---|
| | £ | £ |
| Miscellaneous Revenue— | | |
| Judicial fees | 1,368,400 | 1,380,000 |
| Military exemption fees | 165,700 | 162,400 |
| Interest on investments | 121,000 | 97,000 |
| Rent of State lands | 393,000 * | 174,600 |
| Contributions to pension fund | 77,300 | 131,400 |
| Miscellaneous | 295,600 | 580,700 |
| | 2,421,000 | 2,526,000 |
| State enterprises— | | |
| Railways | 2,990,900 | 3,439,300 |
| Telegraphs | 101,300 | 115,400 |
| Post office | 215,900 | 286,900 |
| | 3,308,100 | 3,841,700 |
| Grand Total | 14,813,300 | 15,965,700 |

There is also an extraordinary revenue, as follows:—

| | 1905. | 1910. |
|---|---|---|
| | £ | £ |
| Revenue on investment of the Reserve Fund | 300,700 | 210,300 |
| Sale of State property | ... * | 109,100 |
| Share in the Daira Sania sale | 1,527,600 | |
| Repayment of advances, etc. | 300,700 | 51,200 |
| Receipts from loans, etc. | 160,700 | 1,400 |
| Total | 2,290,000 | 372,000 |

## Ordinary Expenses.

### I. *Common Benefit.*

| | 1905. | 1910. |
|---|---|---|
| | £ | £ |
| Defence— | | |
| Egyptian Army | 657,600 | 863,200 |
| British Army | 97,500 | 146,300 |
| | 755,100 | 1,009,500 |
| Administration— | | |
| Civil list | 256,400 | 285,700 |
| Foreign affairs | 12,000 | 12,800 |
| Legislature | 14,600 | 22,900 |
| Police, prisons, etc. | 403,400 | 719,300 |
| Collection of revenue | 396,800 | 505,000 |
| | 1,083,200 | 1,545,700 |

* In 1905 the item "rent of State lands" included £256,700, the proceeds of the sale of State lands. From 1908 these sums have been paid directly into the General Reserve.

| | 1905. £ | 1910. £ |
|---|---|---|
| Public debt— | | |
| Tribute to Turkey | 665,000 | 665,000 |
| Guaranteed debt | 307,100 | 307,100 |
| Privileged debt | 1,062,200 | 1,062,200 |
| Unified debt | 2,182,900 | 2,182,900 |
| Caisse de la dette | 35,800 | 34,600 |
| Floating debt | 334,400 | 335,300 |
| | 4,587,500 | 4,587,200 |
| Provinces | 375,400 | 504,300 |
| Public Works— | | |
| Public buildings | 263,900 | 222,700 |
| Various | 180,100 | 248,900 |
| | 444,100 | 471,700 |
| Public health | 178,100 | 291,600 |
| Total, Common Benefit | 7,423,300 | 8,410,000 |
| II. *Reflex Benefit.* | | |
| Education | 146,600 | 481,000 |
| Irrigation | 742,500 | 773,900 |
| Sudan | 193,000 | 198,000 |
| Communications | 82,700 | 103,400 |
| Pensions | 466,800 | 528,500 |
| Various | 190,600 | 260,900 |
| Total, Reflex Benefit | 1,822,200 | 2,345,800 |
| III. *Mixed Benefit.* | | |
| Justice | 532,500 | 705,900 |
| Various | 1,800 | 2,200 |
| Total, Mixed Benefit | 534,300 | 708,000 |
| IV. *Special Benefit.* | | |
| Railways | 1,664,200 | 2,011,800 |
| Telegraphs | 74,700 | 104,300 |
| Post office | 149,700 | 269,900 |
| Total, Special Benefit | 1,888,600 | 2,386,100 |
| Total, ordinary expenditure | 11,668,400 | 13,849,800 |
| To this must be added the special or extraordinary expenditure | 456,400 | 564,600 |
| Making a Grand Total of | 12,124,800 | 14,414,500 |
| Balance carried to the General Revenue | 2,688,500 | 1,551,200 |

*Public Debt.*—The public debt of Egypt commenced in the reign of Said Pasha, at whose death, in 1863, there was a floating debt estimated at between £7,000,000 and £11,000,000.

The reckless finance of his successor, Ismail Pasha, raised the public indebtedness to about £100,000,000 by 1876, and of this amount the country reaped the benefit to the extent of probably only two-fifths, spent on works of public utility. It says much for the intrinsic financial soundness of Egypt that it has in thirty years fully recovered from the incubus of this enormous and for the most part unproductive expenditure.

On December 31, 1910, the position of the debt was as follows:—

| | Interest. | Outstanding. | Annual Charge. | Market Quotation. | Dividends Payable. |
|---|---|---|---|---|---|
| | per cent. | £ | £ | | |
| Unified debt. . | 4 | 55,971,960 | 2,182,906 | 100½ | May 1 and November 1. |
| Privileged debt . | 3½ | 31,127,780 | 1,062,235 | 94½ | April 15 and October 15. |
| Domains loan . | 4¼ | 457,760 | 26,271 | 101 | June 1 and December 1. |
| Guaranteed debt . | 3 | 7,414,700 | 218,913 | 96 | March 1 and September 1. |
| Totals . | ... | 94,972,200 | 3,490,325 | | |

The debt is being gradually paid off, but it is considered sounder finance to expend budgetary surpluses on productive works which return a large percentage profit, than to use them in the reduction of a debt on which the rate of interest does not exceed 4 per cent. The surpluses are paid to the Reserve Fund, which may be regarded as the fund for capital expenditure.

There has also been in recent years a regular extraordinary expenditure charged against the Reserve Fund. This amounted to

£5,818,178 in 1905, and to
£2,533,583 in 1910.

The heaviest items in most years are the expenditure on Public Works and Railways. Particulars concerning public revenue and expenditure will be found in *L'Annuaire Statistique de l'Egypte*, published by the Statistical Department; *Political Economy for Egyptian Students*, by J. A. Todd, p. 267; and in a condensed form in the official Almanac for each year.

At the end of each of the past five years the debt was :—

| | Amount. | Reduction. |
|---|---|---|
| 1905 | £96,483,880 | |
| 1906 | 96,180,660 | £303,220 |
| 1907 | 95,833,280 | 347,380 |
| 1908 | 95,513,460 | 319,820 |
| 1909 | 95,240,740 | 272,720 |
| 1910 | 94,972,200 | 268,540 |

The Domains Loan was paid off during 1912.

There is, in addition to the above consolidated debt, floating debt in the shape of the following annuities—

| | |
|---|---|
| Mukabala (terminates 1930) . . . . . . . | £ (E.) 150,000 |
| Annuity, Kena-Aswan Railway (terminates 1978) . . | 141,761 |
| ,, Ismailia—Port Said Railway (terminates 1968) | 23,010 |
| ,, Aswan Reservoir (terminates 1933) . . . | 153,295 |

Particulars concerning the various loans will be found in *L'Annuaire Statistique de l'Egypte* for 1911, and in *Political Economy*, by J. A. Todd, p. 361.

## CHAPTER II.

# *THE NILE.*

20. Introduction.—21. Nomenclature.—22. Description of the Course of the Nile.—23. Catchment Basins of the Nile.—24. Slopes and Velocities of the Nile in its Different Reaches.—25. The recorded Nile Gauges.—26. Discharge Tables of the Nile Gauges.—27. Discharge of the Nile and its Tributaries.—28. General.

20. **Introduction.**—In the introduction to his brilliant essay on the Hydrology of the Nile,* an essay which, though written in 1865, foreshadowed much of what we know to-day, Lombardini remarked, with much truth, that no river in the world lends itself to hydrological studies on so majestic a scale as the Nile. The most interesting river of the ancient world, it is still the most interesting river of our times; and although much has been done, so that now, at the end of the first decade of the twentieth century, it is possible to frame a just conception of the parts played by the different factors in its economy, there still remains the problem how to make use of this knowledge for the reclamation of the vast plains in the south and the stretches of salted land in the north which await the advent of some engineer gifted with real genius. The engineering problems of the Nile are no whit less enthralling than were the geographical ones.

Lombardini gathered together all the information available at the time that Sir Samuel Baker announced the existence of the Albert Nyanza, shortly after Speke and Grant had proclaimed to the world that the Victoria Nyanza was the true source of the Nile. From the information then available he deduced the laws and operations of the great river. About twenty years later, just before the rebellion in the Sudan closed the Nile to the civilised world, a German savant, Joseph Chavanne,† in his book on the rivers of Africa, collected and tabulated on clear and methodical lines the information available in 1883. The known facts in the hydrology were summarised in the second edition of this work, published in 1898. Since then the chief step in the hydrology of the Nile was marked by the publication of Sir William Garstin's *Report on the Basin of the Upper Nile.* ‡

* *Saggie idrolico sul Nilo*, by Elia Lombardini, Milan, 1865.

† *Afrikas Ströme und Flüsse*, by Joseph Chavanne, Wien, 1883.

‡ *Report on the Basin of the Upper Nile*, by Sir William Garstin, Blue Book, Egypt (2), 1904. London, 1904.

The information made available by the last work has been discussed from the standpoint of the engineer by one of us,* and from the geographical point of view by Capt. H. G. Lyons, R.E.† The latter has collected and summarised a mass of information from previous authors on this aspect of the river. An excellent and concise statement of the purely hydrographic aspect has recently appeared from the pen of Dr Walter Pietsch,‡ and though some of his facts are now known to be wrong, his method is clear and correct.

21. **Nomenclature.**—The usual nomenclature of the tributaries of the Nile is difficult to follow. In this book we shall call the river the Victoria Nile from Lake Victoria to Lake Albert; the Albert Nile from Lake Albert to the Sobat mouth (this reach is known generally as the Bahr el Jebel); the White Nile from the Sobat mouth to Khartoum; and the Nile from Khartoum to the sea. The Blue Nile stretches from Lake Tsana in Abyssinia to Khartoum.

22. **Description of the Course of the Nile.**—The Nile drains nearly the whole of North-eastern Africa, an area comprising nearly three million square kilometres, of which, however, only 50 per cent. may be considered as effectively contributing to the discharge. Its basin may be divided into three main parts—the Equatorial basin feeding the Albert Nile and Bahr el Ghazal; the Abyssinian basin, with its main drainage channels, the Sobat, the Blue Nile, and the Atbara; and finally the Desert basin. In this last reach the Nile has no tributary, but flows through its 2760 kilometres to the sea, a solitary stream, traversing one of the greatest deserts on the globe, and the sole source of life and vigour to whatever exists on its banks.

These three regions have distinctly different pluviometric regimes. The plateau of the great lakes enjoys the double rainy season of the Equator; the uplands of Abyssinia come under the influence of the Africo-Asiatic monsoon; and the last reaches lie in the belt of the steady, drying trade-winds. It is to these north and south trade-wind belts that the great problems of irrigation have so far been confined. How to draw for the benefit of the dry zone on the excessive rainfall in the South is the question before us to-day, and we are working in the regions of heavy rainfall near the Equator and in the vast accumulations of water in the Egyptian Sudan.

The longest tributary, the White Nile, has its furthest sources in south latitude 2°·5, near Lake Kivu. Known as the Kagera, it is the principal feeder of Lake Victoria, and has a course of about 850 kilometres§ before it reaches the lake.‖ The other fifteen chief affluents of the lake have

* *The Nile in* 1904, by Sir William Willcocks, London, 1904.

† *Physiography of the River Nile and its Basin*, by Capt. H. G. Lyons, F.R.S., R.E., Cairo, 1906.

‡ *Das Abflussgebiet des Nils*, by Dr Walter Pietsch, Berlin, 1910.

§ Distances in this section are approximate.

‖ Pietsch, *Abflussgebiet des Nils*, p. 13.

lengths of from 30 to 210 kilometres, and are most of them little more than mountain torrents.

Lake Victoria, covering 67,000 square kilometres, is the first reservoir of the Nile. The Victoria Nile leaves the lake by the Ripon Falls, and after a course of 390 kilometres enters Lake Albert at its northern corner. At its southern end, Lake Albert is fed by the Semliki River, which rises in Lake Edward. Its own area is 4500 square kilometres.

The Albert Nile leaves Lake Albert at its northern end, and has a course of 1290 kilometres to the mouth of the Sobat. Of this length the first 200 kilometres up to Nimulé have scarcely any slope and few feeders of any magnitude: in the next 150 kilometres the river falls 150 metres over a series of severe cataracts and rapids which form an insuperable barrier to navigation between Lake Albert and the lower river. In this last reach it is fed by some important feeders, notably the Assua, whose flood waters have a marked effect on the Albert Nile. From the foot of this cataract reach, the Albert Nile has a fair slope and traverses the Sudd region, where the channel has often been barred by blocks of living vegetation. In this latter region, the stream is divided into two main channels, the right-hand one of which is known as the Bahr el Zeraf. After a course of 290 kilometres, the Bahr el Zeraf joins the Albert Nile again. In the interval, the Albert Nile receives, as a left-hand feeder, the Bahr el Ghazal. The Sobat River, which has its sources in Gallaland, is the first tributary of the Abyssinian system. It joins the Albert Nile at the north-eastern corner of the depression through which flow the latter and the Bahr el Ghazal. From the junction of the Albert Nile and the Sobat, the river, known now as the White Nile, flows in a very gently sloping channel 850 kilometres long to Khartoum, where it joins the Blue Nile.

The Blue Nile is the true parent of the land of Egypt. The deposits of its muddy waters have made the land. The Atbara has added its quota, but the Blue Nile is the chief contributor. Fed by the timely and plentiful rains of central and western Abyssinia, it contributes two-thirds of the waters which pass Aswan. The furthest sources are those of the Abai, which, after a course of 110 kilometres, falls into Lake Tsana. This lake has an area of 3000 square kilometres, and lies about 1760 metres above sea-level. The Blue Nile leaves it at its south-eastern corner and hurries down to the Sudan, fed by numerous Abyssinian rivers. At Roseires, after a course of 900 kilometres, it has fallen 1260 metres; and below the Roseires cataract enters the plain country south of Khartoum. For its remaining 615 kilometres on to Khartoum, where it meets the White Nile, it is navigable for half the year. North of Sennar it is fed by the Dinder and Rahad Rivers.

Between Khartoum and Atbara, on a length of 325 kilometres, the Nile

has its even passage broken by the so-called Sixth Cataract at Shabluka. At Atbara the Nile receives the Atbara as a right-hand tributary.

The Atbara is a very muddy torrent fed by the rains of North-eastern Abyssinia. It runs for four months per annum, and is practically dry for eight months. Rising within a few kilometres of Lake Tsana, it falls 1500 metres in its first 300 kilometres, and is then joined by the Bahr el Salaam, and, 100 kilometres lower down, by the Settit River. After the junction with the Settit, the Atbara hurries down for 480 kilometres, and joins the Nile at Atbara, contributing a fair quantity of water and a very considerable quantity of Nile mud to the river.

At Atbara the river enters the third region of its course, and thenceforth receives no tributary in the 2760 kilometres to the sea.

In its first length of 1550 kilometres to Aswan it traverses the Fifth and Fourth Cataracts between Berber and Dongola, the Third and Second Cataracts between Dongola and Wadi Halfa, and the First Cataract at Aswan. All these cataracts are navigable in flood, but not so in low supply. From Aswan to the Barrage at the head of the Delta, the Nile has a length of 970 kilometres, and traverses Egypt without a cataract or natural interruption of any kind. At the Delta Barrage, the Nile divides into the Rosetta and Damietta branches, and after a further course of about 240 kilometres in either branch, flows into the Mediterranean sea. Its total length from the sources of the Kagera River to the sea is 6700 kilometres, constituting it one of the longest rivers in the world.

The following tables give the distances in kilometres, the reduced levels of high flood and low summer, the reduced levels of the zeros of the gauges where known, the gauge readings in certain cases, the ground levels where of use to the engineer, and in certain cases the bed levels, of:—

Table 61, the Victoria, Albert, and White Niles.
„ 62, the Blue Nile.
„ 63, the Main Nile, Khartoum to Aswan.
„ 64, „ „ „ Aswan to the Barrage.
„ 65, the Damietta Branch.
„ 66, the Rosetta Branch.

We have considered it convenient to give this information in tables, rather than in longitudinal sections. The sections have of necessity to be so reduced in scale that no useful measurements can be taken. Given in large-type figures in tables, they can be readily utilised without the aid of magnifying glasses.

In Table 61 we note that the range between high and low supply at Mongalla on the Albert Nile is 2·1, falling to 0·5 at the Zeraf head, and even to 0·2 at Buffalo Cape, south of Lake No. The channel of the

TABLE 61.—DISTANCES IN KILOMETRES AND HIGH AND LOW LEVELS ALONG THE VICTORIA, ALBERT, AND WHITE NILES.

| Locality. | Distance from the Source. | Reduced Levels. | | | Gauge Readings. | | Range between High and Low Supply. | |
|---|---|---|---|---|---|---|---|---|
| | | Lowest Summer. | Highest Flood. | Zero of Gauge. | From | To | | |
| | km. | | | | | | | |
| Kagera source . | ... | ... | ... | ... | ... | ... | ... | |
| Kagera mouth . | 850 | 1131 | ... | ... | ... | ... | ... | |
| Ripon Falls . . | 1084 | 1131 | Lake | Victoria | ... | ... | ... | |
| Kakoji . . . | 1148 | (1037) | ... | ... | ... | ... | ... | |
| Lake Choga . . | 1196 | (1035) | ... | ... | ... | ... | ... | |
| Mruli . . . | 1283 | 1031 | ... | ... | ... | ... | ... | Victoria Nile. |
| Foweira . . . | 1358 | (1027) | ... | ... | ... | ... | ... | |
| Murchison Falls . | 1437 | 659·5 / 622·0 | ... | ... | ... | ... | ... | |
| | | (Mean low supply) | (Mean flood) | | | | | |
| Lake Albert . . | 1475 | 618·1 | 618·6 | ... | ... | ... | ... | |
| Wadelai . . | 1541 | ... | ... | ... | ... | ... | ... | |
| | | (Mean) | | | | | | |
| Nimulé . . . | 1693 | 609·3 | ... | ... | ... | ... | ... | |
| Fort Berkeley . . | 1841 | (455·1) | ... | ... | ... | ... | ... | |
| Gondokoro . | 1873 | 452·47 | 454·43 | 441·83 | 10·5 | 13·5 | 2·0 | |
| Lado . . . | 1885 | ... | ... | ... | ... | ... | ... | |
| Mongalla . . | 1913 | 442·15 | 444·28 | 431·12 | 10·5 | 13·5 | 2·1 | |
| Giggings. . . | 1978 | ... | ... | ... | 10·5 | 12·5 | ... | |
| Bor . . . | 2038 | 421·86 | 422·80 | 411·21 | 10·5 | 12·5 | 0·9 | |
| Ghaba Shambe . | 2221 | 407·08 | 408·21 | 396·16 | 10·5 | 12·5 | 1·1 | Albert Nile. |
| Ghaba el Inderab . | 2315 | 403·00 | 403·54 | 391·96 | 10·5 | 12·0 | 0·5 | |
| Zeraf Head . . | 2328 | 402·43 | 402·97 | 392·43 | 10·5 | 12·0 | 0·5 | |
| Hillet Nuer . . | 2415 | 398·53 | 399·16 | 387·64 | 10·5 | 12·0 | 0·6 | |
| Buffalo Cape . . | 2592 | 390·76 | 390·96 | 379·35 | 11·0 | 12·2 | 0·2 | |
| Lake No . . | 2640 | 388·68 | 389·47 | 375·23 | 12·5 | 14·5 | 0·8 | |
| Khor Yergol . . | 2675 | 387·69 | 389·08 | 374·48 | 13·2 | 14·9 | 1·4 | |
| Attigo . . . | 2705 | 386·80 | 386·71 | 375·25 | 11·5 | 13·5 | 1·9 | |
| Zeraf mouth . . | 2720 | 386·51 | 388·70 | 375·40 | 11·0 | 13·5 | 2·2 | |
| Fenikang . . | 2745 | 385·67 | 388·51 | 374·94 | 10·5 | 13·5 | 2·8 | |
| Sobat mouth . . | 2767 | 385·07 | ... | ... | ... | ... | ... | |
| Taufikia . . . | 2775 | 384·96 | 388·36 | 375·26 | 9·5 | 13·5 | 3·4 | |
| Malakal . . . | 2790 | 384·78 | 388·04 | 375·00 | 9·5 | 13·5 | 3·3 | |
| Kodok . . . | 2865 | 384·02 | 387·28 | 374·20 | 9·5 | 13·5 | 3·3 | |
| Melut . . . | 2940 | 383·09 | 386·23 | 373·30 | 9·5 | 13·5 | 3·1 | White Nile. |
| Renk . . . | 3125 | 381·12 | 383·73 | 371·21 | 9·5 | 13·0 | 2·6 | |
| Hillet Abbas . . | 3285 | 378·26 | 381·39 | 368·31 | 9·5 | 13·5 | 3·1 | |
| Kosti Railway Bridge | 3290 | ... | ... | ... | ... | ... | ... | |
| Dueim . . . | 3405 | 377·20 | 381·58 | 367·46 | 9·5 | 15·5 | 4·4 | |
| Geteina . . . | 3520 | 376·01 | 381·43 | 366·01 | 9·5 | 15·5 | 5·4 | |
| Khartoum . . | 3615 | 374·63 | 381·55 | 364·82 | 9·5 | 17·5 | 6·9 | |

*N.B.*—In the Sudan the zero of the gauge is always called 10·00 metres, to avoid negative readings.

Albert Nile can carry a certain quantity of water, and, as it is deltaic in its traverse of the Sudd region, all excess water flows away through the papyrus into the marshes. This is one of the principal keys to the proper comprehension of the Sudd region, and this point will be returned to in CHAPTERS III. and XII.

Lake No has had a range of only 0·8 metre in the six or seven years it has been gauged. This is important.

From Melut to Khartoum the White Nile is a long lake rather than a river. Its level in high floods depends on the height of the Blue Nile and not on that of the Albert Nile or the Sobat.

The Blue Nile is a torrent, and so is the Atbara. The Main Nile from Khartoum to Aswan has a vast storage of water power, which may be utilised one day.

The 1892 flood levels of the Nile from Aswan northwards were very carefully recorded by the engineers of the Aswan Reservoir Survey and the irrigation engineers, and all connected by levelling. They are of real value when any effort is made to calculate highest flood levels.

TABLE 62.—BLUE NILE, GIVING DISTANCES FROM LAKE TSANA; AND REDUCED LEVELS IN THE LOWER REACHES, IN METRES ABOVE MEAN SEA.

| Locality. | Distance from Lake Tsana, in km. | Reduced Level. | |
|---|---|---|---|
| | | Mean Low Supply. | Mean Flood. |
| Lake Tsana . . . | 0 | 1755* | 1756·5* |
| Muger mouth . . | 315* | | |
| Durra mouth . . . | 560* | | |
| Didessa mouth . . | 635* | | |
| Yabus mouth . . . | 760* | | |
| Bolassa mouth . . | 805* | | |
| Fazogli . . . . | 875* | 477* | 489* |
| Roseires . . . | 975* | 441·4 | 452·2 |
| Abu Naama . . . | 1098 | | |
| Singa . . . . | 1170 | 416·9 | 427·9 |
| Shellal Abdin . . | 1223 | | |
| Sennar . . . . | 1263 | 409·2 | 417·1 |
| Wad Abbas . . . | 1300 | | |
| Dinder mouth . . | 1358 | | |
| Wad Medani . . . | 1417 | 391·1 | 401·1 |
| Rahad mouth . . | 1425 | | |
| Rufaa . . . . | 1464 | | |
| Kamlin . . . . | 1517 | 382·9 | 391·5 |
| Khartoum (gauge) . . | 1621 | 374·3 | 381·0 |
| ,, (confluence) . | 1623 | 374·1 | 380·8 |

* These distances from Lake Tsana and altitudes are very approximate.

The gentle slope of the Nile flood from Gebel Silsila to Naga Hammadi is instructive. All the canals in this reach have also gentle slopes

On the Damietta branch the high flood of 1892 was 3·1 metres above ground-level in the reach north of Zifta. On the corresponding reach north of Kafr Zayat, on the Rosetta branch, the difference was only 2·0 metres.

Table 63.—The Main Nile from Khartoum to Aswan, giving Distances along the Centre Line of the Flood, and Reduced Levels in Metres above Mean Sea-level.

| Locality. | Distance from the source of the Kagera. | Reduced Levels. | | | Distance along the Steamer Track. | | |
|---|---|---|---|---|---|---|---|
| | | Flood, 1878. | Mean Low Supply (11 years). | Ground. | From the Aswan Dam. | From Khartoum Confluence. | |
| Khartoum (confluence) . . | km. 3615 | ... | 374·1 | 382 | 1873 | km. 0 | |
| Tamaniat . . | 3660 | ... | 370·0 | 377 | 1828 | 45 | approx. |
| Shabluka . . | 3695 | ... | 365·5 | 374 | 1793 | 80 | |
| Shendi . . | 3803 | ... | 354·6 | 364 | 1685 | 188 | |
| Atbara . . | 3940 | ... | 344·8 | 352 | 1548 | 325 | |
| Berber . . | 3980 | ... | 339·6 | 349 | 1508 | 365 | |
| Abu Hamed . | 4191 | ... | 311·0 | 315 | 1297 | 576 | |
| Kareima . . | 4428 | ... | 244·1* | 253 | 1060 | 813 | |
| Dongola . . | 4702 | ... | 223·0 | 236 | 786 | 1087 | |
| Hannek . . | ... | ... | 216·7 | 224 | 726 | 1147 | |
| Kaibar . . | 4823 | ... | 202·6 | 218 | 665 | 1208 | |
| | | | (1872–1902) | | | | |
| Wadi Halfa . . | 5148 | 126·5 | 117·9 | 127·0 | 340 | 1533 | |
| *Kilometres from Aswan dam—* | | | | | | | |
| Kilometre 300 . | 5188 | 122·6 | 113·6 | 123·2 | 300 | 1573 | Kilometres counted from the Aswan dam in column 1. |
| Abu Simbel . | 5208 | ... | ... | ... | 280 | 1593 | |
| Toski . . . | 5238 | ... | ... | ... | 250 | 1623 | |
| Kilometre 250 . | 5238 | 118·6 | 108·6 | 118·5 | 250 | 1623 | |
| Ibrim . . . | 5261 | ... | ... | ... | 227 | 1646 | |
| Der . . . | 5280 | ... | ... | ... | 208 | 1665 | |
| Kilometre 200 . | 5288 | 114·6 | 104·3 | 115·0 | 200 | 1673 | |
| Korosko . . | 5302 | ... | ... | ... | 186 | 1687 | |
| Kilometre 150 . | 5338 | 111·0 | 100·8 | 112·0 | 150 | 1723 | |
| Dekka . . | 5379 | ... | ... | ... | 109 | 1764 | |
| Kilometre 100 . | 5388 | 107·7 | 97·3 | 108·0 | 100 | 1773 | |
| Kalabsha . . | 5431 | ... | ... | ... | 57 | 1816 | |
| Kilometre 50 . | 5438 | 104·9 | 93·3 | 105·0 | 50 | 1823 | |
| Aswan dam . . | 5488 | 99·8 | 90·2 | 100·5 | 0 | 1873 | |
| Aswan Nilometer | 5493 | 94·15 | 85·0 | 93·6 | 5 | 1878 | |

* Doubtful.

TABLE 64.—THE MAIN NILE FROM ASWAN NILOMETER TO THE BARRAGE, GIVING THE DISTANCES ALONG THE CENTRE LINE OF THE FLOOD IN KILOMETRES; AND REDUCED LEVELS IN METRES ABOVE MEAN SEA-LEVEL.

| Locality. | Distance from Source, in kilometres. | Reduced Levels, in metres. | | | | | Slope of Water Surface. | Distances in kilometres along Steamer Track. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Flood, 1892. | Flood, 1888. | Low Mean Summer. | Bed. | Ground. | | From Aswan. | From Barrage. |
| Aswan | 5493 | 93·9 | 92·1 | 85·0 | 81·5 | 93·6 | 1/11,500 | 0 | 968 |
| Kom Ombo | 5535 | ... | ... | ... | ... | ... | | 43 | 925 |
| Kilometre 50 | 5543 | 89·6 | 88·5 | 80·9 | 73·8 | 89·7 | | | |
| Gebel Silsila | 5560 | ... | ... | ... | ... | ... | | 70 | 898 |
| Kilometre 70 | 5563 | 87·8 | 87·0 | 79·3 | 72·3 | 87·8 | | | |
| Ramadi Head | 5573 | ... | .. | ... | ... | ... | 1/14,800 | | |
| Kilometre 100 | 5593 | 85·2 | 84·3 | 77·2 | 74·2 | 85·1 | | | |
| Edfu | 5598 | ... | ... | ... | ... | ... | | 109 | 859 |
| El Kab | 5618 | ... | ... | ... | ... | ... | | | |
| Kilometre 150 | 5643 | 82·7 | 80·5 | 73·6 | 70·5 | 81·9 | | | |
| Esna Barrage | 5652 | ... | ... | ... | ... | ... | | 169 | 805 |
| Mataana | 5660 | ... | ... | ... | ... | ... | | | |
| Armant | 5688 | ... | ... | ... | ... | ... | | 200 | 768 |
| Kilometre 200 | 5693 | 79·2 | 77·2 | 69·8 | 64·2 | 78·5 | | | |
| Luxor | 5706 | ... | ... | ... | ... | ... | | 219 | 749 |
| Shanuria Canal | 5726 | ... | ... | ... | ... | ... | | | |
| Kilometre 250 | 5743 | 75·8 | 73·8 | 66·7 | 62·5 | 73·3 | | | |
| Kena | 5767 | ... | ... | ... | ... | ... | | 283 | 685 |
| Kilometre 300 | 5793 | 72·3 | 70·1 | 63·0 | 59·0 | 71·3 | | | |
| Kilometre 330 | 5823 | 69·8 | 67·6 | 61·1 | 50·0 | 68·7 | 1/12,200 | | |
| Naga Hammadi Br. | 5825 | ... | ... | ... | ... | ... | | | |
| Kilometre 350 | 5843 | 68·5 | 66·4 | 59·0 | 54·1 | 68·3 | | | |
| Abu Shusha | 5857 | ... | ... | ... | ... | ... | | | |
| Balyana | 5866 | ... | ... | ... | ... | ... | | 389 | 579 |
| Girga | 5882 | ... | .. | ... | ... | ... | | 407 | 561 |
| Kilometre 400 | 5893 | 64·7 | 62·5 | 56·1 | 52·9 | 64·7 | | | |
| Sohag | 5921 | ... | ... | ... | ... | ... | | 448 | 520 |
| Kilometre 450 | 5943 | 60·6 | 58·5 | 51·8 | 45·8 | 60·3 | | | |
| Kilometre 470 | 5963 | 58·8 | 56·5 | 49·9 | 45·6 | 58·4 | 1/11,800 | | |
| Khazindaria Canal | 5964 | ... | ... | ... | ... | ... | | | |
| Kilometre 500 | 5993 | 56·3 | 53·8 | 47·8 | 41·0 | 56·0 | | | |
| Abu Tig Escape | 5997 | ... | ... | ... | ... | ... | | | |
| Assiut Barrage | 6020 | ... | ... | ... | ... | ... | | 548 | 420 |
| Kilometre 530 | 6023 | 53·8 | 51·2 | 45·6 | 34·1 | 53·5 | | | |

TABLE 64—*continued.*

| Locality. | Distance from Source, in kilometres. | Reduced Levels, in metres. | | | | | Slope of Water Surface. | Distances in kilometres along Steamer Track. | |
|---|---|---|---|---|---|---|---|---|---|
| | | Flood, 1892. | Flood, 1888. | Low Mean Summer. | Bed. | Ground. | | From Aswan. | From Barrage. |
| Kilometre 550 | 6043 | 51·8 | 49·3 | 43·6 | 37·1 | 51·7 | 1/11,000 | | |
| Manfalut | 6055 | ... | ... | ... | ... | ... | | 591 | 377 |
| Gebel Abu Foda | 6064 | ... | ... | ... | ... | ... | | | |
| Deirut Escape | 6091 | ... | ... | ... | ... | ... | | 628 | 340 |
| Kilometre 600 | 6093 | 47·1 | 44·8 | 38·9 | 32·0 | 48·5 | | | |
| Roda | 6119 | ... | ... | ... | ... | ... | | 660 | 308 |
| Kilometre 650 | 6143 | 42·4 | 40·4 | 34·2 | 31·0 | 42·5 | | | |
| Minia | 6159 | ... | ... | ... | ... | ... | | 700 | 268 |
| Kolosna | 6186 | ... | ... | ... | ... | ... | | | |
| Kilometre 700 | 6193 | 38·1 | 36·0 | 29·7 | 27·5 | 37·3 | | | |
| Kilometre 710 | 6203 | 37·2 | 35·0 | 28·9 | 24·0 | 36·5 | | | |
| Maghagha | 6224 | ... | ... | ... | ... | ... | 1/11,000 | | |
| Kilometre 750 | 6243 | 33·4 | 31·2 | 25·6 | 22·0 | 32·1 | | | |
| Feshn | 6245 | ... | ... | ... | ... | ... | | | |
| Biba | 6257 | ... | ... | ... | ... | ... | | | |
| Beni Suef | 6277 | ... | ... | ... | ... | ... | | 825 | 143 |
| Kilometre 800 | 6293 | 28·9 | 26·6 | 20·7 | 18·7 | 27·7 | 1/11,600 | | |
| Koshesha Escape | 6306 | ... | ... | ... | ... | ... | | | |
| Wasta | 6311 | ... | ... | ... | ... | ... | | 860 | 108 |
| Girza Canal | 6323 | ... | ... | ... | ... | ... | | | |
| Kilometre 850 | 6343 | 24·1 | 21·5 | 16·0 | 12·8 | 23·3 | | | |
| El Ayat | 6345 | ... | ... | ... | ... | ... | | 895 | 73 |
| Badreshein | 6371 | ... | ... | ... | ... | ... | | | |
| Kilometre 880 | 6373 | 21·8 | 19·0 | 13·6 | 6·5 | 20·8 | 1/10,800 | 922 | 46 |
| Cairo, Roda Gauge | 6389 | ... | ... | ... | ... | ... | | | |
| Cairo | 6393 | 20·5 | 18·0 | 12·0 | 5·0 | 19·3 | | 945 | 23 |
| Delta Barrages | 6415 | 18·5 | 16·5 | 11·2* | 9·0 | 16·2 | | 968 | 0 |

* If the Barrages were open in summer.

TABLE 65.—THE DAMIETTA BRANCH OF THE NILE FROM THE BARRAGE TO THE SEA, GIVING DISTANCES ALONG THE CENTRE LINE OF THE FLOOD, AND REDUCED LEVELS IN METRES ABOVE MEAN SEA.

| Locality. | Distances from the Source of the Nile, in kilometres. | Reduced Levels. | | | Distances in kilometres. | | Slope of Water Surface in Flood. |
|---|---|---|---|---|---|---|---|
| | | Flood, 1892. | Ground. | Bed. | From the Barrage. | From the Sea. | |
| Delta Barrage | 6415 | 18·2 | 16·8 | 10·0 | 0 | 242 | 1/13,000 |
| Kilometre 30 | ... | 16·0 | 13·6 | 6·7 | ... | ... | |
| Benha | 6463 | ... | ... | ... | 48 | 194 | |
| Kilometre 50 | ... | 14·5 | 12·2 | 4·9 | ... | ... | |
| Mitbera | 6476 | ... | ... | ... | 61 | 181 | 1/13,900 |
| Kilometre 80 | ... | 12·3 | 9·8 | 3·3 | ... | ... | |
| Zifta | 6500 | ... | ... | ... | 85 | 157 | |
| Zifta Barrage | ... | ... | ... | ... | 90 | 152 | |
| Kilometre 100 | ... | *10·9* | *7·8* | 2·5 | ... | ... | 1/13,900 |
| Samanud | 6538 | ... | ... | ... | 123 | 119 | |
| Kilometre 130 | ... | 8·7 | 6·3 | 0 | ... | ... | |
| Mansura | 6553 | ... | ... | | 138 | 104 | |
| Kilometre 150 | ... | 7·3 | 4·5 | Below sea level. | ... | ... | 1/12,000 |
| Sherbin | 6587 | ... | ... | | 172 | 70 | |
| Kilometre 180 | ... | 5·0 | 3·2 | | ... | ... | |
| Kilometre 200 | ... | 3·1 | 2·0 | | ... | ... | |
| Faraskur | 6623 | ... | ... | | 208 | 34 | Temporary dam. 1/13,600 |
| Kilometre 210 | ... | 2·5 | 1·7 | | ... | ... | |
| Damietta | 6639 | ... | ... | | 224 | 18 | |
| The Sea | 6657 | 0·0 | 0·0 | | 242 | 0 | |

The maximum height of flood above ground in 1892 was at Kilometre 100, where it was 3·1 metres.

TABLE 66.—THE ROSETTA BRANCH OF THE NILE FROM THE BARRAGE TO THE SEA, GIVING DISTANCES ALONG THE CENTRE LINE OF THE FLOOD, AND REDUCED LEVELS IN METRES ABOVE MEAN SEA-LEVEL.

| Locality. | Distances from the Source of the Nile, in kilometres. | Reduced Levels. | | | Distances in kilometres. | | Slope of Water Surface in Flood. |
|---|---|---|---|---|---|---|---|
| | | Flood, 1892. | Ground. | Bed. | From the Barrage. | From the Sea. | |
| Delta Barrage | 6415 | 18·0 | 16·4 | 9·0 | 0 | 236 | 1/12,700 |
| Kilometre 30 | ... | 15·8 | 13·8 | 6·9 | ... | ... | |
| Wardan | 6446 | ... | ... | ... | 31 | 205 | |
| Khatatba | 6460 | ... | ... | .. | 45 | 191 | |
| Kilometre 50 | ... | 14·1 | 12·9 | 5·0 | ... | ... | 1/12,800 |
| Nadir | 6491 | ... | ... | ... | 76 | 160 | |
| Kilometre 80 | ... | 12·3 | 10·3 | *0·0* | ... | ... | |
| Tanub | 6513 | ... | ... | | 98 | 138 | |
| Kilometre 100 | ... | 10·2 | 8·6 | Below sea level. | ... | ... | 1/16,700 |
| Kafr Zayat | 6535 | 9·3 | 7·3 | | 120 | 116 | |
| Kilometre 130 | ... | 8·8 | 6·8 | | ... | ... | |
| Kuddaba | 6555 | ... | ... | | 140 | 96 | |
| Kilometre 150 | ... | 7·2 | 5·5 | | ... | ... | 1/12,200 |
| Shibrakhît | 6573 | ... | ... | | 158 | 78 | |
| Desûk | 6585 | 5·6 | 3·4 | | 170 | 66 | |
| Kilometre 180 | ... | 5·0 | 3·1 | | ... | ... | |
| Fua | 6600 | ... | ... | | 185 | 51 | |
| Mahmudia | 6604 | ... | ... | | 189 | 47 | |
| Kilometre 200 | ... | 3·1 | 1·6 | | ... | ... | 1/11,600 |
| Mehallet el Amar | 6623 | ... | ... | | 208 | 28 | |
| Kilometre 210 | ... | 2·5 | 0·9 | | ... | ... | |
| Rosetta | 6636 | ... | ... | | 221 | 15 | |
| The Sea | 6651 | 0·0 | 0·0 | | 236 | 0 | |

23. **The Catchment Basins of the Nile.**—We have divided the basin of the Nile into three main parts—the Equatorial, the Abyssinian, and the Desert basins. These must be further subdivided for adequate study as follows:—

I. Equatorial Basin.
- (1) Lake Victoria.
- (2) Victoria Nile.
- (3) Western Lakes.
- (4) Upper Albert Nile.
- (5) Lower Albert Nile and Bahr el Zeraf.
- (6) Bahr el Ghazal.

| | |
|---|---|
| II. Abyssinian Basin. | (7) Sobat.<br>(8) White Nile.<br>(9) Blue Nile.<br>(10) Atbara. |
| III. Desert Basin. | (11) Without tributaries. |

Large portions of these basins are, however, non-effective as catchment areas, and in the third column of the following table we have given an estimate of the effective portion of each.

TABLE 67.—AREAS OF THE CATCHMENT BASINS OF THE NILE.

| | Total Area. Square km. | Effective Area. Square km. | Effective Volume of Rain. Cubic km. | Effective Mean Rainfall. m. | Cubic Metres per Second Discharged. | Percentage of Rainfall. |
|---|---|---|---|---|---|---|
| *I. Equatorial Basin—* | | | | | | |
| (1) Lake Victoria . | 246,000 | 246,000 | 297 | 1·21 | 610 | 6·5 |
| (2) Victoria Nile . . | 77,000 | 77,000 | 90 | 1·17 | | |
| (3) Western Lakes . | 52,000 | 52,000 | 67 | 1·29 | 790 | 5·0 |
| (4) Upper Albert Nile . | 105,000 | 105,000 | 104 | 0·99 | 1070 | 6·0 |
| (5) Lower Albert Nile and Bahr el Zeraf. | 115,000 | 115,000 | 102 | 0·89 | 490 | 2·3 |
| (6) Bahr el Ghazal . | 564,000 | 370,000 | 335 | 0·91 | 20 | 0·2 |
| *II. Abyssinian Basin—* | | | | | | |
| (7) Sobat . . . . | 154,000 | 138,000 | 150 | 1·09 | 470 | 9·8 |
| (8) White Nile . . | 393,000 | 68,000 | 47 | 0·69 | 800 | 2·1 |
| (9) Blue Nile . . | 277,000 | 277,000 | 307 | 1·11 | 2100 | 21·5 |
| (10) Atbara . . . | 177,000 | 157,000 | 116 | 0·74 | 360 | 9·7 |
| *III. Desert Basin—* | | | | | | |
| (11) Without tributaries. | 721,000 | nil | nil | nil | | |
| Grand Total . | 2,881,000 | 1,605,000 | 1615 | 1·01 | 3080 | 6·0 |

24. **Slopes and Velocities of the Nile in its Different Reaches.**— The altitudes of the surface at low water will be found in Tables 61 to 66. They depend:—

(i.) On the line of levels run from the sea to Wadi Halfa by Sir William Willcocks, which have lately been verified by a careful chain of levelling executed by the Survey Department. According to Mr B. F. E. Keeling, who superintended the latter, the differences between the two chains are immaterial.

(ii.) On the double line of levels run from Wadi Halfa to Khartoum by the Cataract Survey under Mr E. M. Dowson.

(iii.) On the levels run by the Sudan Irrigation Department from Khartoum up both branches of the river and finally through Uganda to Nimulé.

(iv.) On the lines executed in Uganda by Mr L. B. Weldon of the Egyptian Survey Department.

Some of the earlier values are largely conjectural: these are indicated by brackets. With these exceptions only such altitudes are given as are known from spirit-levelling either from the Indian Ocean or from the Mediterranean Sea. There is at present a gap in the chain from sea to sea, as the portions between Nimulé and Fajao or Butiaba have not been completed. It is probable that the Mediterranean Sea and Indian Ocean (at its mean level) do not form portions of the same level surface, but that the former is some 24 centimetres below the latter.* Moreover, the altitudes given are the sums of the observed differences, uncorrected for the ellipticity of the level surfaces, and require positive corrections for reference to mean sea-level at the equator. It so happens that these two adjustments are nearly equal in magnitude and opposite in sign in the neighbourhood of the lakes, and the observed altitudes may be used for the comparison, without sensible error. We may bridge the gap provisionally, as follows:—

The slope of the 212 kilometres from Lake Albert to Nimulé, calculated from Mr Craig's discharge at Wadelai, works out to $\frac{1}{27500}$. This gives a fall of 7·7 metres between the Albert Lake and Nimulé. This is not exact —*e.g.*, the fall indicated in Table 61 of paragraph 22.

The Victoria Nile falls 513 metres in 625 kilometres and has four reaches, with the following slopes:—

(i.) To Kakoji 147 centimetres per kilometre, or $\frac{1}{700}$.

(ii.) To Foweira 10 " " " " $\frac{1}{10000}$.

(iii.) Past the Murchison Falls.

(iv.) To Lake Albert 10 centimetres per kilometre, or $\frac{1}{10000}$.

The Albert Nile falls 233 metres in 1290 kilometres, in six reaches:—

(i.) To Nimulé 2·8 centimetres per kilometre, or $\frac{1}{35500}$.

(ii.) Over the Fola and following cataracts 104 centimetres per kilometre, or $\frac{1}{960}$.

(iii.) From Fort Berkeley to Bor 17 centimetres per kilometre, or $\frac{1}{6000}$.

(iv.) To Ghaba Shambe 8 centimetres per kilometre, or $\frac{1}{12500}$.

(v.) To Lake No 4·6 centimetres per kilometre, or $\frac{1}{22000}$.

(vi.) Below Lake No 2·8 centimetres per kilometre, or $\frac{1}{35500}$.

The White Nile has its behaviour clearly shown in the following table:—

* Keeling, "Relative Heights of the Red and Mediterranean Seas," *Cairo Scientific Journal*, iii. p. 252. The Red Sea is not higher than the Indian Ocean, since an appreciable current flows inwards at the Straits of Bab-el-Mandeb. The Mediterranean Sea is probably 17 centimetres below the level of the Atlantic (Pizzetti, *Geodesia Teoretica*, Bologna, 1905, p. 237).

TABLE 68.—THE WHITE NILE.

| Reach of River. | Length in kilometres. | Low Supply. | | Flood. | |
|---|---|---|---|---|---|
| | | Fall in metres. | Slope. | Fall in metres. | Slope. |
| Malakal to Renk . . | 335 | 3·66 | $\frac{1}{91,000}$ | 4·31 | $\frac{1}{78,000}$ |
| Renk to Dueim . . . | 280 | 3·92 | $\frac{1}{70,000}$ | 2·15 | $\frac{1}{130,000}$ |
| Dueim to Khartoum . . | 210 | 2·57 | $\frac{1}{80,000}$ | ·03 | level |
| Malakal to Khartoum . | 825 | 10·15 | $\frac{1}{80,000}$ | 6·49 | $\frac{1}{130,000}$ |

In low supply the river has a general fall of $\frac{1}{80000}$, but in flood the slope diminishes steadily as we go north, until in the last 250 kilometres it is practically a lake, held up by the Blue Nile flood at Khartoum.

The Blue Nile falls 1381 metres in 1620 kilometres, which may roughly be divided into three reaches:—

(i.) From Lake Tsana to Roseires with a slope of 134 centimetres per kilometre, or $\frac{1}{750}$.

(ii.) From Roseires to Senaar, 11·2 centimetres per kilometre, or $\frac{1}{9000}$.

(iii.) From Sennar to Khartoum, 9·7 centimetres per kilometre, or $\frac{1}{10000}$.

The Main Nile from Khartoum to Aswan falls 289 metres in 1878 kilometres; the so-called six cataracts occupy 565 kilometres with a slope of $\frac{1}{3000}$; and the ordinary channel occupies 1313 kilometres and has a slope of $\frac{1}{13000}$. From Aswan dam to the Barrage, on a length of 973 kilometres, the Nile falls 79 metres with a mean slope of $\frac{1}{12300}$. The Rosetta and Damietta branches are each about 240 kilometres long and have a slope in flood of $\frac{1}{13000}$, and of $\frac{1}{12500}$ in extraordinarily high floods.

From the sources of the Kagera River to the sea, on a length of 6660 kilometres, the Nile falls 2000 metres, or has a slope of $\frac{1}{3200}$. From Lake Victoria to the sea the length is 5573 kilometres and the fall 1131 metres, or the average slope is $\frac{1}{5000}$.

Table 69 gives the velocities of the river month by month, in kilometres per day, and Table 70 the time occupied in traversing the different reaches. We have not given detailed figures for the Victoria Nile, for the interest of the irrigation engineer begins at Lake Albert. From Lake Victoria to Kakoji the velocity is 80 kilometres per day, and the water takes 1·5 days to do the distance. As the Victoria Nile traverses the eastern arm of the many-armed and peculiar Lake Choga with a

Table 69.—Velocity of the Nile in its Different Reaches. (Km. per day.) (Average year.)

| Locality. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake Albert to Nimulé | 53 | 52 | 51 | 50 | 51 | 52 | 54 | 57 | 59 | 60 | 59 | 58 |
| Nimulé to Fort Berkeley | 69 | 66 | 62 | 60 | 62 | 65 | 69 | 73 | 77 | 80 | 77 | 75 |
| Fort Berkeley to Bor | 86 | 81 | 77 | 75 | 78 | 82 | 88 | 94 | 98 | 100 | 98 | 94 |
| Bor to Ghaba Shambe | 69 | 66 | 62 | 61 | 61 | 65 | 69 | 73 | 77 | 80 | 77 | 75 |
| Ghaba Shambe to Lake No | ← | | | | | | 60 | | | | | → |
| Lake No to Sobat Mouth | ← | | | | | | 35 | | | | | → |
| Sobat Mouth to Hillet Abbas | 43 | 39 | 35 | 32 | 30 | 32 | 34 | 38 | 42 | 46 | 49 | 49 |
| Hillet Abbas to Khartoum | ← | | | | | | 30 | | | | | → |
| Khartoum to Shabluka | 95 | 84 | 77 | 71 | 72 | 83 | 115 | 136 | 139 | 131 | 115 | 104 |
| Sixth Cataract | 140 | 125 | 110 | 100 | 110 | 125 | 150 | 175 | 200 | 190 | 180 | 160 |
| Sixth Cataract to Atbara | 95 | 84 | 77 | 71 | 72 | 83 | 115 | 136 | 140 | 131 | 115 | 104 |
| Atbara to Fifth Cataract | 95 | 84 | 77 | 71 | 72 | 83 | 115 | 136 | 140 | 131 | 115 | 104 |
| Fifth Cataract | 140 | 125 | 110 | 100 | 105 | 120 | 145 | 170 | 195 | 195 | 185 | 165 |
| Fifth Cataract to Fourth Cataract | 108 | 95 | 87 | 76 | 83 | 88 | 106 | 125 | 146 | 147 | 140 | 125 |
| Fourth Cataract | 140 | 125 | 110 | 100 | 105 | 120 | 145 | 170 | 195 | 195 | 185 | 165 |
| Fourth Cataract to Third Cataract | 109 | 96 | 80 | 77 | 82 | 87 | 105 | 124 | 144 | 146 | 141 | 126 |
| Third Cataract | 132 | 116 | 107 | 93 | 97 | 103 | 124 | 147 | 173 | 176 | 170 | 152 |
| Third Cataract to Second Cataract | 132 | 116 | 107 | 93 | 97 | 103 | 124 | 147 | 173 | 176 | 170 | 152 |
| Second Cataract | 140 | 125 | 110 | 100 | 105 | 120 | 145 | 170 | 195 | 195 | 185 | 165 |
| Wadi Halfa to Aswan Dam | 90 | 80 | 75 | 60 | 60 | 65 | 90 | 130 | 145 | 140 | 125 | 105 |
| Aswan Dam to Aswan Gauge | 130 | 120 | 115 | 110 | 105 | 105 | 120 | 170 | 195 | 195 | 185 | 160 |
| Aswan Gauge to Delta Barrage | 112 | 103 | 96 | 90 | 85 | 81 | 84 | 100 | 130 | 150 | 140 | 125 |
| Delta Barrage to Sea | 112 | 103 | 96 | 90 | 85 | 81 | 84 | 100 | 130 | 150 | 140 | 125 |

Strictly the velocity depends on the gauges, and this table should be used in conjunction with gauge readings to get the best results.

TABLE 70.—TIME IN WHICH THE WATER TRAVELS (in days) FROM LOCALITY TO LOCALITY.

| Locality. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake Albert to Nimulé . . . | 4·1 | 4·2 | 4·3 | 4·4 | 4·3 | 4·2 | 4·0 | 3·8 | 3·7 | 3·6 | 3·7 | 3·9 |
| Nimulé to Fort Berkeley . . . | 2·1 | 2·3 | 2·4 | 2·5 | 2·4 | 2·3 | 2·1 | 2·0 | 1·9 | 1·9 | 1·9 | 2·0 |
| Fort Berkeley to Bor . . . | 2·3 | 2·4 | 2·5 | 2·6 | 2·5 | 2·4 | 2·3 | 2·2 | 2·1 | 2·0 | 2·1 | 2·2 |
| Bor to Ghaba Shambe. . . . | 2·7 | 2·8 | 2·9 | 3·0 | 3·0 | 2·8 | 2·7 | 2·5 | 2·4 | 2·3 | 2·4 | 2·5 |
| Ghaba Shambe to Lake No. . . | ← 7 → | | | | | | | | | | | |
| Lake No to Sobat Mouth . . . | ← 3·6 → | | | | | | | | | | | |
| Sobat Mouth to Hillet Abbas . . | 12·0 | 13·3 | 14·8 | 16·2 | 17·3 | 16·2 | 15·2 | 13·6 | 12·3 | 11·3 | 10·6 | 10·6 |
| Hillet Abbas to Khartoum . . . | ← 11·0 → | | | | | | | | | | | |
| Khartoum to Shabluka . . . | 0·8 | 1·0 | 1·1 | 1·2 | 1·1 | 1·0 | 0·7 | 0·6 | 0·6 | 0·6 | 0·7 | 0·8 |
| Sixth Cataract . . . . . . | ← 0·1 → | | | | | | | | | | | |
| Sixth Cataract to Atbara . . . | 2·4 | 2·7 | 3·0 | 3·2 | 3·1 | 2·7 | 2·0 | 1·7 | 1·6 | 1·7 | 2·0 | 2·2 |
| Atbara to Fifth Cataract . . . | 0·5 | 0·6 | 0·7 | 0·8 | 0·7 | 0·6 | 0·5 | 0·4 | 0·4 | 0·4 | 0·4 | 0·5 |
| Fifth Cataract . . . . . . | 1·1 | 1·3 | 1·5 | 1·6 | 1·5 | 1·3 | 1·1 | 0·9 | 0·8 | 0·8 | 0·9 | 1·0 |
| Fifth Cataract to Fourth Cataract . | 0·9 | 1·0 | 1·1 | 1·3 | 1·2 | 1·1 | 0·9 | 0·8 | 0·7 | 0·6 | 0·7 | 0·8 |
| Fourth Cataract . . . . . | 0·8 | 0·9 | 1·0 | 1·1 | 1·0 | 0·9 | 0·8 | 0·6 | 0·5 | 0·5 | 0·6 | 0·7 |
| Fourth Cataract to Third Cataract . | 2·9 | 3·3 | 3·5 | 4·1 | 3·8 | 3·6 | 3·0 | 2·5 | 2·2 | 2·1 | 2·2 | 2·5 |
| Third Cataract . . . . . . | 0·6 | 0·7 | 0·8 | 0·9 | 0·8 | 0·8 | 0·7 | 0·6 | 0·5 | 0·5 | 0·5 | 0·5 |
| Third Cataract to Second Cataract . | 0·8 | 0·9 | 1·0 | 1·2 | 1·1 | 1·0 | 0·9 | 0·7 | 0·6 | 0·6 | 0·7 | 0·7 |
| Second Cataract . . . . . | 1·4 | 1·6 | 1·8 | 2·0 | 1·9 | 1·7 | 1·4 | 1·2 | 1·0 | 1·0 | 1·1 | 1·2 |
| Wadi Halfa to Aswan Dam . . . | 3·8 | 4·3 | 4·6 | 5·7 | 5·7 | 5·3 | 3·8 | 2·7 | 2·2 | 2·4 | 2·8 | 3·3 |
| Aswan Dam to Delta Barrage . . | 8·6 | 9·4 | 10·1 | 10·8 | 11·4 | 12·0 | 11·5 | 9·7 | 7·5 | 6·5 | 6·9 | 7·8 |
| Delta Barrage to Sea . . . . | 2·1 | 2·3 | 2·4 | 2·6 | 2·8 | 2·9 | 2·8 | 2·4 | 1·8 | 1·6 | 1·7 | 1·9 |

perceptible current, and as, moreover, the lake is very shallow, we may give some value to the velocity and make it half that of the Bahr el Ghazal, which is 0·20 metre per second and is considered perceptible. With a velocity of 0·10 metre per second, or 8 kilometres per day, the 80 kilometres of the lake would be traversed in ten days. From Lake Choga to the Albert Lake the velocity is about 80 kilometres per day, and the time of traverse three to three and a half days. The time of traverse from Lake Victoria to Lake Albert would be fifteen days. With Lake Albert it is very different. It takes the Victoria Nile five months to fill up Lake Albert before the Albert Nile can carry off the waters of the Victoria Nile, gauge for gauge. Under these conditions it will be wise to stop at Lake Albert and begin a new calculation from this lake.

The Albert Nile takes twenty-two days in flood and twenty-five days in low supply to traverse the distance from Lake Albert to the Sobat mouth. The White Nile takes twenty-one days in flood and twenty-eight days in extreme low supply to reach Khartoum. Consequently from Lake Albert to Khartoum we have forty-three days in flood and fifty-three days in low supply.

From Khartoum to Aswan the Nile takes eleven days in flood and twenty-two days in low supply, and consequently from Lake Albert to Aswan we have fifty-four days in flood and seventy-five days in low supply.

From Aswan to Cairo we have six days in flood and twelve days in low supply.

Table 71 is very interesting and well worth study. Through the Sudd region we have a velocity of 0·7 metre per second, but only of 0·35 metre per second in the White Nile. In Egypt the Nile in flood has a velocity of 1·75 metres per second, and in low supply of 0·85 metre per second.

The lake and river gauges which exist at the present time (1912) are given in Table 72.

The river gauges which are not read daily are given in Table 73.

TABLE 71.—TIME-TABLE OF MOVEMENT OF WATER DOWN THE NILE. (Mean Year.)

| Locality | | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. | XI. | XII. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lake Albert | leaves | Jan. 1 | Feb. 1 | Mar. 1 | Apr. 1 | May 1 | June 1 | July 1 | Aug. 1 | Sept. 1 | Oct. 1 | Nov. 1 | Dec. 1 |
| Nimulé | arrives | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Fort Berkeley | ,, | 7 | 8 | 8 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 7 |
| Bor | ,, | 9 | 10 | 10 | 10 | 10 | 10 | 9 | 9 | 9 | 9 | 9 | 9 |
| Ghaba Shambé | ,, | 12 | 13 | 13 | 13 | 13 | 13 | 12 | 12 | 11 | 11 | 11 | 12 |
| Lake No | ,, | 19 | 19 | 19 | 20 | 20 | 19 | 18 | 18 | 18 | 17 | 18 | 18 |
| Sobat Mouth | ,, | 23 | 23 | 24 | 24 | 24 | 23 | 23 | 22 | 22 | 21 | 22 | 22 |
| Hillet Abbas | ,, | Feb. 4 | Mar. 9 | Apr. 8 | May 11 | June 10 | July 9 | Aug. 6 | Sept. 4 | Oct. 3 | Nov. 1 | Dec. 2 | Jan. 2 |
| Khartoum | ,, | 15 | 20 | 19 | 22 | 21 | 20 | 17 | 15 | 14 | 12 | 13 | 13 |
| Shabluka | ,, | 16 | 21 | 20 | 23 | 22 | 21 | 18 | 16 | 15 | 13 | 14 | 14 |
| Atbara | ,, | 19 | 24 | 24 | 26 | 24 | 23 | 20 | 17 | 17 | 15 | 17 | 17 |
| Fourth Cataract | ,, | 22 | 28 | 27 | 29 | 27 | 25 | 22 | 19 | 19 | 17 | 19 | 19 |
| Kareima | ,, | 23 | 29 | 28 | 31 | 28 | 26 | 22 | 20 | 19 | 18 | 20 | 20 |
| Third Cataract | ,, | 26 | Apr. 2 | May 2 | June 3 | July 2 | 29 | 25 | 22 | 21 | 20 | 22 | 23 |
| Second Cataract | ,, | 28 | 4 | 5 | 5 | 4 | 31 | 26 | 23 | 22 | 21 | 23 | 24 |
| Wadi Halfa | ,, | Mar. 2 | 5 | 7 | 7 | 5 | Aug. 1 | 27 | 24 | 23 | 22 | 24 | 26 |
| Aswan Dam | ,, | 6 | 11 | 12 | 12 | 9 | 5 | 30 | 26 | 26 | 25 | 28 | 30 |
| Esna Barrage | ,, | 8 | 12 | 13 | 14 | 10 | 7 | Sept. 1 | 27 | 27 | 26 | 30 | 31 |
| Assiut Barrage | ,, | 10 | 15 | 16 | 17 | 13 | 9 | 2 | 29 | 29 | 28 | Jan. 1 | Feb. 3 |
| Delta Barrages | ,, | 17 | 21 | 23 | 24 | 20 | 15 | 5 | Oct. 3 | Nov. 2 | Dec. 3 | 5 | 8 |
| Mediterranean Sea | ,, | ... | ... | ... | ... | ... | 17 | 6 | 5 | 4 | 5 | 7 | ... |

1

TABLE 72.—LAKE AND RIVER GAUGES IN THE NILE BASIN.

| Portion of Basin. | Place. | Nature of Gauge. | Approximate Reading, High Stage. | Approximate Reading, Low Stage. | Level of Zero above Sea-level. | Remarks. |
|---|---|---|---|---|---|---|
| | | | metres | metres | metres | |
| Lake Victoria . | Kisumu (Port Florence) . | Wooden | 1·50 | 0·00 | 1131·20 | Above mean sea-level at Mombasa. |
| | Entebbe . . . . . | ,, | 1·40 | 0·30 | 1130·90 | ,, ,, ,, |
| | Jinja . . . . . | ,, | 1·40 | 0·15 | 1131 app. | ,, ,, ,, |
| Lake Albert . | Butiaba . . . . . | ,, | 1·30 | 0·80 | 617·35 | ,, ,, ,, |
| Albert Nile . | Koba . . . . . | ,, | 0·61 | 0·10 | 618 app. | ,, ,, ,, |
| | Gondokoro . . . . | Masonry | 12·54 | 10·90 | 441·83 | ,, ,, Alexandria. |
| | Mongalla . . . . . | ,, | 13·02 | 11·20 | 431·12 | ,, ,, ,, |
| | Giggings . . . . . | ,, | 12·46 | 11·00 | ? | ,, ,, ,, |
| | Bor . . . . . | ,, | 11·53 | 11·00 | 411·21 | ,, ,, ,, |
| | Ghaba Shambé. . . | ,, | 11·81 | 11·10 | 396·16 | ,, ,, ,, |
| | Attigo . . . . . | ,, | 13·06 | 11·60 | 375·25 | ,, ,, ,, |
| Bahr el Ghazal | Wau (Jur River) . . | ,, | 14·60 | 10·00 | ? | |
| | Meshra el Rek . . . | ,, | 2·08 | 1·10 | ? | |
| River Sobat . | Gambela (Baro River) | Wooden | 4·73 | 0·00 | ? | |
| | Abwong . . . . . | Masonry | ... | 9·60 | ? | |
| | Doleib Hill . . . . | ,, | 13·87 | 10·70 | 375·43 | ,, ,, ,, |
| White Nile . | Taufikia . . . . . | ,, | 12·52 | 9·70 | 375·26 | ,, ,, ,, |
| | Malakal . . . . . | ,, | 12·46 | 10·20 | 375·00 | ,, ,, ,, |
| | Kodok . . . . . | ,, | 12·50 | 9·80 | 374·20 | ,, ,, ,, |
| | Melut . . . . . | ,, | 12·39 | 9·80 | 373·30 | ,, ,, ,, |
| | Renk . . . . . | ,, | 12·00 | 9·90 | 371·21 | ,, ,, ,, |

TABLE 72.—LAKE AND RIVER GAUGES IN THE NILE BASIN (*continued*).

| Portion of Basin. | Place. | Nature of Gauge. | Approximate Reading, High Stage. | Approximate Reading, Low Stage. | Level of Zero above Sea-level. | Remarks. |
|---|---|---|---|---|---|---|
| | | | metres | metres | metres | |
| White Nile (*continued*) | Hillet Abbas | Masonry | 12·68 | 10·00 | 368·31 | Above mean sea-level at Alexandria |
| | Dueim | ,, | 13·93 | 9·90 | 367·21 | ,, ,, ,, |
| | Geteina | ,, | 14·83 | 10·00 | 366·00 | ,, ,, ,, |
| Blue Nile | Roseires | ,, | 20·84 | 10·00 | 431·41 | ,, ,, ,, |
| | Abu Hashim (Dinder River) | ,, | 16·84 | 9·60 | 413·91 | ,, ,, ,, |
| | Singa | ,, | 20·97 | 10·00 | 406·91 | ,, ,, ,, |
| | Mafaza (Rahad River) | ,, | 16·69 | 12·30 | 416·91 | ,, ,, ,, |
| | Sennar | ,, | 18·04 | 10·10 | 399·11 | ,, ,, ,, |
| | Wad Medani | ,, | 19·35 | 9·50 | 381·61 | ,, ,, ,, |
| | Kamlin | ,, | 18·13 | 9·50 | 373·41 | ,, ,, ,, |
| | Khartoum | ,, | 16·14* | 9·50 | 364·82 | ,, ,, ,, |
| River Atbara | Khashm el Girba | Cut in rock | 15·42 | 9·00 | ? | |
| Nile | Omdurman | Masonry | 16·00 | 9·60 | 364·52 | ,, ,, ,, |
| | Tamaniat | ,, | 16·00 | 9·75 | 360·13 | ,, ,, ,, |
| | Shendi | ,, | 17·49 | 10·90 | 343·76 | ,, ,, ,, |
| | Atbara | ,, | 15·91 | 9·90 | 334·84 | ,, ,, ,, |
| | Abu Hamed | ,, | 13·95 | 9·90 | 301·18 | ,, ,, ,, |
| | Merowe | ,, | 18·77 | 9·90 | 237·73 | ,, ,, ,, |
| | Argo | ,, | 15·20 | 10·20 | 213·77 | ,, ,, ,, |
| | Wadi Halfa | ,, | 8·15 | 0·60 | 116·70 | ,, ,, ,, |
| | Aswan (D.S. of Dam) | ,, | 92·57* | 84·50 | sea-level | Readings are with reference to sea-level |
| | Assiut (D.S.) | ,, | 51·89 | 45·19 | ,, | ,, ,, ,, |
| | Roda (Cairo) | ,, | 19·93* | 14·42† | ,, | ,, ,, ,, |
| | Delta Barrages (U.S.) | ,, | 17·30* | 14·30† | ,, | ,, ,, ,, |
| | Zifta Barrage ,, | ,, | ... | ... | ,, | ,, ,, ,, |

* The highest known floods have been at Khartoum, R.L. 382·40 metres; at Aswan, R.L. 94·15 metres; at Roda (Cairo), R.L. 21·27 metres; at the Delta Barrage, R.L., 18·61 metres.

† With the Barrages closed.

TABLE 73.—RIVER GAUGES IN THE NILE BASIN NOT READ DAILY.

| Portion of Basin. | Place. | Nature of Gauge. | Approximate Reading, High Stage. | Approximate Reading, Low Stage. | Level of Zero above Sea-level. | Remarks. |
|---|---|---|---|---|---|---|
| | | | metres | metres | metres | |
| Albert Nile | Ghaba el Inderab (325 km. U.S. of Lake No) | Masonry | 11·50 | 11·20 | Unfixed | |
| | Hillet Nuer (225 km. U.S. of Lake No) | ,, | 11·50 | 11·20 | ,, | |
| | Buffalo Cape (48 km. U.S. of Lake No) | ,, | 11·60 | 11·40 | 379·35 | Above mean sea-level at Alexandria. |
| Bahr el Zeraf | Kilometres 50 from tail | ,, | 15·00 | 12·30 | 375·35 | ,, ,, ,, |
| | ,, 100 | ,, | 16·70 | 13·60 | 375·51 | ,, ,, ,, |
| | ,, 150 | ,, | 18·00 | 15·70 | ... | ,, ,, ,, |
| | ,, 188 (Meshra Kwatch) | ,, | 21·00 | 18·50 | 375·11 | ,, ,, ,, |
| | ,, 235 (Ajwong) | ,, | 23·00 | 21·80 | 375·26 | ,, ,, ,, |
| | ,, 266 | ,, | 25·80 | 24·50 | 375·26 | ,, ,, (calculated). |
| | ,, 285 | ,, | 27·50 | 26·50 | 375·26 | ,, ,, at Alexandria. |
| Albert Nile | Lake No | ,, | 13·80 | 13·40 | 375·23 | ,, ,, ,, |
| | Khor Yergol (25 km. D.S. of Lake No) | ,, | 14·00 | 13·20 | 374·48 | ,, ,, ,, |
| | Zeraf mouth (89 km. D.S. of Lake No) | ,, | 12·50 | 11·10 | 375·40 | ,, ,, ,, |
| | Fenikang (105 km. D.S. of Lake No) | ,, | 12·80 | 10·80 | 374·94 | ,, ,, ,, |
| Blue Nile | Hillet Hassan (about 15 km. U.S. of Sennar) | ,, | 20·00 | 12·50 | 397·87 | ,, ,, ,, |
| | Dail el Meshaikh | ,, | 17·00 | 9·50 | 398·07 | ,, ,, ,, |

25. **The Recorded Nile Gauges.**—In the preceding paragraph we have given the names, positions, and levels of the more important Nile gauges read in the Sudan and in Egypt. We now give the gauges for some typical years.

Figs. 13 and 14 give the gauges for 1911, 1912, and the mean to 1911 from first date of reading of:

*Kisumu* on Lake Victoria, which gives the discharge entering the Victoria Nile.

*Butiaba* on Lake Albert, which gives the discharge entering the Albert Nile.

*Mongalla* on the Albert Nile, which tells us the discharge entering the Sudd region.

*Gambela* on the Baro, the principal tributary of the Sobat River.

*Malakal* on the White Nile, which tells us the discharge leaving the Sudd region with the addition of the supply brought down by the Sobat.

*Roseires* on the Blue Nile, which is a measure of the Blue Nile supply.

*Kamlin* on the Blue Nile, which gives the discharge of the Blue Nile where it meets the White.

*Khartoum* on the Blue Nile, just above the junction of the Blue and White Niles, which is a measure of the water entering the Main Nile, but not an exact measure, as it is in a backwater.

*Tamaniat* on the Main Nile downstream of Omdurman, which gives the discharge of the joint waters of the Blue and White Niles.

*Khashm el Girba* on the Atbara, which gives the discharge of the Atbara.

*Wadi Halfa* on the Main Nile, which gives the discharge of the water entering Egypt. Low discharges are affected by silt and scour.

*Aswan* (Elephantine gauge), which gives the discharge of the river as affected by the Aswan reservoir.

*Roda* (*Cairo*), which gives a measure of the water passing Cairo. This gauge is just upstream of the Delta Barrages, and is no gauge of the quantity of water in the river, except during high floods when the Barrage is fully open.

We also give the following gauge readings:—

*Mongalla* and *Ghaba Shambé* gauges on the Albert Nile. Ten-day means for 1909 (a high year), 1911, and 1912, and the mean of six years.

*Buffalo Cape*, *Lake No*, and *Fenikang* on the tail reach of the Albert Nile round Lake No, reduced levels for 1909, 1910, 1912, and the mean of four years. The fall of the water-level is so insignificant that reduced levels are more convenient. A very high year on the Albert Nile, like 1909, and a very low year, like 1912, show little difference in this reach of the Albert Nile downstream of the Sudd region. Lake No and Fenikang are more affected by backwater from the Sobat than from any other cause.

*Doleib Hill* at the tail of the Sobat River. Gauges for 1909, 1910, 1911, and 1912 are given. This gauge is in a backwater.

*Malakal* near the head of the White Nile.

*Kamlin* gauge on the Blue Nile about 200 kilometres above Khartoum and out of reach of any backwater. The daily means for 1909, 1911, 1912, and the mean of six years to 1911.

*Khartoum gauge.* Ten-day means, 1909, 1911, 1912, and the mean of six years to 1911.

*Khashm el Girba* for 1909, 1910, 1911, and 1912.

*Wadi Halfa,* 1892, 1894, 1898, 1899, 1907, 1908, 1911, 1912, and the mean of fifteen years 1890–1904.

*Aswan* (Elephantine). Five-day means for 1892, 1907, 1908, 1912, and the mean of thirty years, 1873 to 1902. The year 1892 was a very high year, while 1912 was exceedingly low. Since the reservoir has been working, *i.e.* since 1903, the bed of the river opposite the gauge at Elephantine Island has been very considerably scoured, and gauge for gauge more water passes to-day there than previous to 1903.

*Assiut Barrage.* The Assiut gauge for 1892 stood on the river. In 1903 the Barrage was first utilised, and regulated on both in summer and in flood when necessary.

The up- and downstream gauges are given for five-day means during 1907, 1908, and 1912, and the river for 1892. The upstream gauges are a measure of the water entering the Ibrahimia Canal, and the downstream gauges of the water passing on to Lower Egypt.

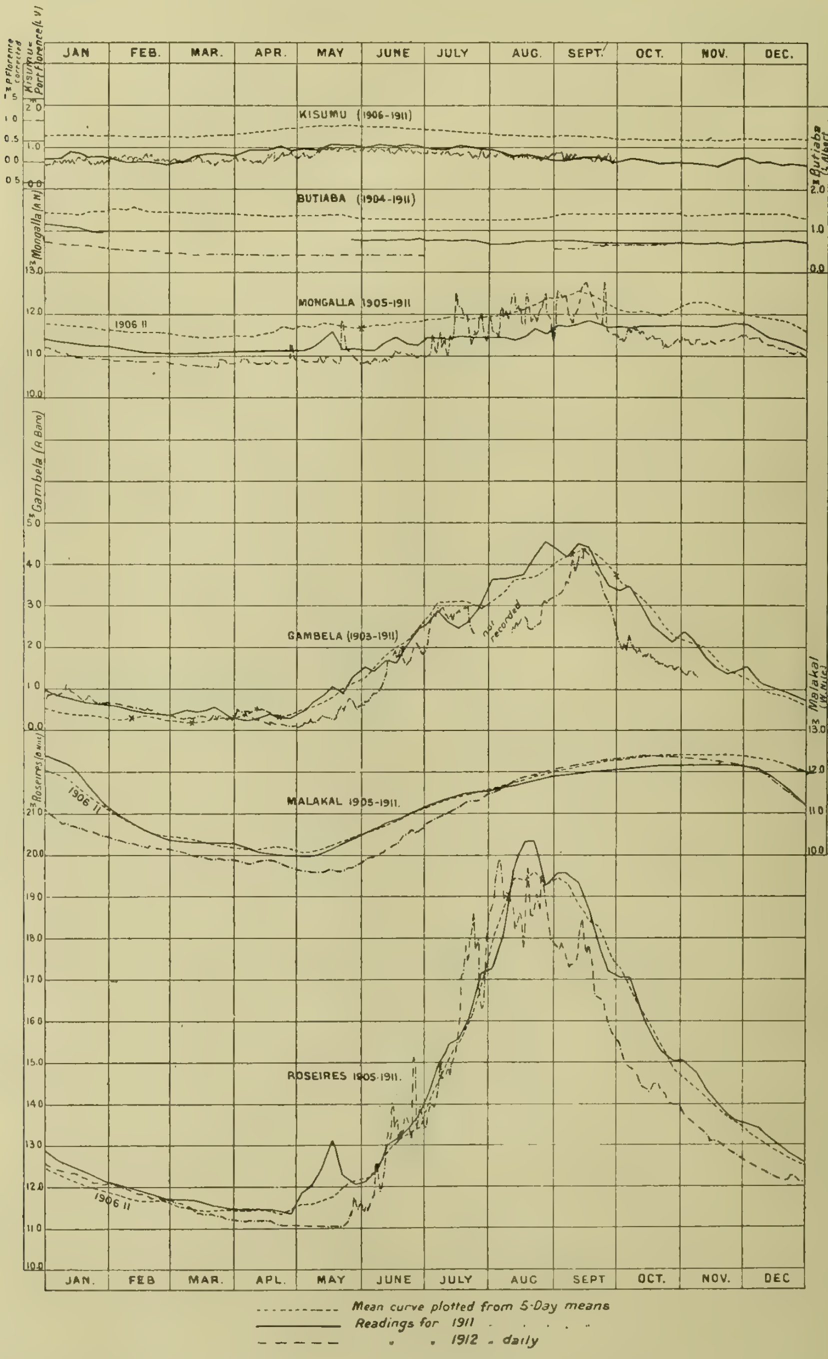
*Cairo* (*Roda*). Five-day mean gauges for 1892, 1907, 1908, 1912, and the mean of thirty-eight years (1873-1910). The Delta Barrage was first used for regulation during flood time in 1902 by Sir Hanbury Brown, K.C.M.G.

*Delta Barrage.* Five-day means are given for 1892, 1907, 1908, and 1912, of the upstream gauge at the Rosetta branch Barrage. These gauges are a measure of the water entering the Lower Egypt canals.

*Tamaniat.* Ten-day means, 1912.

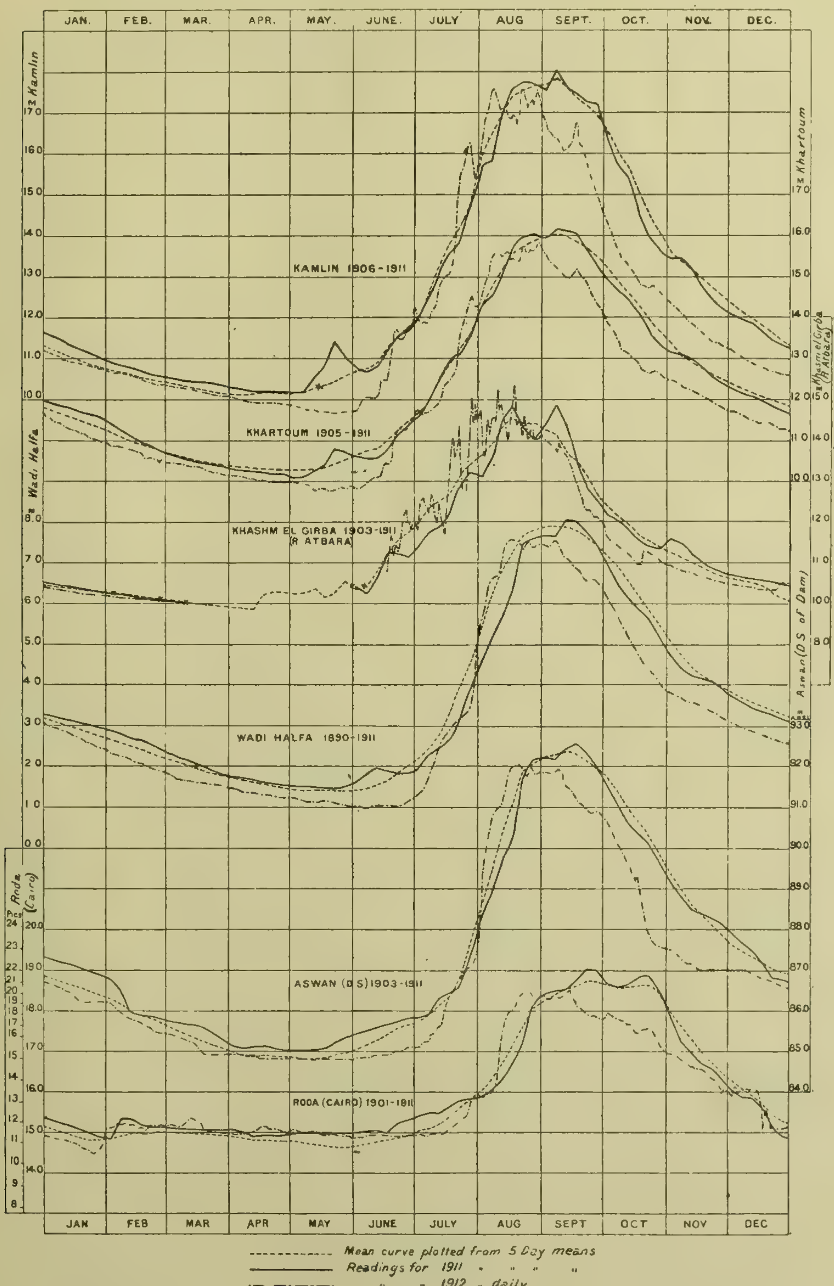
Gauge readings for Roseires will be found in Appendix VII., in which will also be found gauge readings for 1913.

[TABLE



JAN
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
KISUMU (1906-1911)
BUTIABA (1904-1911)
MONGALLA 1905-1911
1906 11
GAMBELA (1903-1911)
not recorded
MALAKAL 1905-1911.
1906 11
ROSEIRES 1905-1911.
1906 11
Kisumu-Port Florence (L.V.)
Mongalla (B.N.)
Gambela (R. Baro)
Roseires (B. Nile)
Butiaba (L. Albert)
Malakal (W. Nile)
JAN.
FEB
MAR.
APL.
MAY
JUNE
JULY
AUG
SEPT
OCT.
NOV.
DEC
Mean curve plotted from 5-Day means
Readings for 1911
" " 1912 " daily


FIG. 13.



JAN. FEB. MAR. APR. MAY. JUNE. JULY AUG SEPT. OCT. NOV. DEC.
KAMLIN 1906-1911
KHARTOUM 1905-1911
KHASHM EL GIRBA 1903-1911 (R ATBARA)
WADI HALFA 1890-1911
ASWAN (D S) 1903-1911
RODA (CAIRO) 1901-1911
Kamlin
Wadi Halfa
Roda (Cairo)
Pics
Khartoum
Khashm el Girba (R Atbara)
Aswan (D S of Dam)
Mean curve plotted from 5 Day means
Readings for 1911 " " "
" " 1912 " daily


FIG. 14.

TABLE 74.—ALBERT NILE GAUGES AT MONGALLA.
(Ten-day means in metres.)

| Date. | | 1909. | 1911. | 1912. | Mean, 1906–1911. |
|---|---|---|---|---|---|
| January | 5 | 11·51 | 11·35 | 11·15 | 11·78 |
| | 15 | 11·49 | 11·27 | 10·99 | 11·73 |
| | 25 | 11·47 | 11·22 | 10·91 | 11·67 |
| February | 5 | 11·42 | 11·19 | 10·87 | 11·62 |
| | 15 | 11·37 | 11·11 | 10·86 | 11·58 |
| | 25 | 11·33 | 11·05 | 10·84 | 11·57 |
| March | 5 | 11·29 | 11·03 | 10·78 | 11·52 |
| | 15 | 11·28 | 11·06 | 10·74 | 11·48 |
| | 25 | 11·30 | 11·07 | 10·80 | 11·48 |
| April | 5 | 11·45 | 11·09 | 10·84 | 11·51 |
| | 15 | 11·52 | 11·10 | 10·81 | 11·55 |
| | 25 | 11·90 | 11·10 | 10·90 | 11·66 |
| May | 5 | 12·04 | 11·15 | 10·86 | 11·71 |
| | 15 | 11·80 | 11·48 | 10·91 | 11·84 |
| | 25 | 11·76 | 11·15 | 11·11 | 11·75 |
| June | 5 | 11·91 | 11·12 | 10·86 | 11·70 |
| | 15 | 12·00 | 11·37 | 10·97 | 11·76 |
| | 25 | 11·74 | 11·28 | 11·09 | 11·80 |
| July | 5 | 11·79 | 11·45 | 11·19 | 11·87 |
| | 15 | 12·24 | 11·44 | 11·72 | 11·92 |
| | 25 | 12·14 | 11·44 | 11·61 | 11·90 |
| August | 5 | 11·95 | 11·45 | 11·81 | 11·98 |
| | 15 | 12·17 | 11·46 | 12·14 | 12·09 |
| | 25 | 12·17 | 11·59 | 11·98 | 12·29 |
| September | 5 | 12·38 | 11·72 | 12·16 | 12·40 |
| | 15 | 12·83 | 11·82 | 12·42 | 12·53 |
| | 25 | 12·92 | 11·72 | 11·72 | 12·26 |
| October | 5 | 12·49 | 11 69 | 11·54 | 12·04 |
| | 15 | 11·90 | 11·70 | 11·48 | 12·03 |
| | 25 | 11·64 | 11·71 | 11·30 | 12·04 |
| November | 5 | 11·56 | 11·70 | 11·36 | 12·25 |
| | 15 | 11·84 | 11·71 | 11·32 | 12·22 |
| | 25 | 11·72 | 11·76 | 11·30 | 12·09 |
| December | 5 | 11·70 | 11·67 | 11·42 | 11·97 |
| | 15 | 11·65 | 11·42 | 11·23 | 11·85 |
| | 25 | 11·60 | 11·25 | 11·08 | 11·75 |
| Means | | 11·81 | 11·31 | 11·26 | 11·85 |

Zero of gauge R.L. 431·12, 10 metres below the original zero of 441·12.

TABLE 75.—ALBERT NILE GAUGES AT GHABA SHAMBÉ.
(Ten-day means in metres.)

| Date. | | 1909. | 1911. | 1912. | Mean, 1906–1911. |
|---|---|---|---|---|---|
| January | 5 | 11·39 | 11·48 | 11·17 | 11·53 |
| | 15 | 11·33 | 11·37 | 11·13 | 11·47 |
| | 25 | 11·24 | 11·29 | 11·10 | 11·42 |
| February | 5 | 11·18 | 11·22 | 11·03 | 11·37 |
| | 15 | 11·16 | 11·16 | 10·90 | 11·34 |
| | 25 | 11·13 | 11·11 | 10·80 | 11·31 |
| March | 5 | 11·11 | 11·07 | 10·74 | 11·29 |
| | 15 | 11·08 | 11·00 | 10·66 | 11·26 |
| | 25 | 11·08 | 10·99 | 10·60 | 11·24 |
| April | 5 | 11·08 | 10·96 | 10·57 | 11·21 |
| | 15 | 11·17 | 10·94 | 10·58 | 11·21 |
| | 25 | 11·18 | 10·92 | 10·51 | 11·18 |
| May | 5 | 11·18 | 10·97 | 10·62 | 11·21 |
| | 15 | 11·21 | 11·00 | 10·55 | 11·24 |
| | 25 | 11·32 | 11·05 | 10·61 | 11·29 |
| June | 5 | 11·40 | 11·13 | 10·65 | 11·33 |
| | 15 | 11·40 | 11·20 | 10·73 | 11·38 |
| | 25 | 11·39 | 11·19 | 10·72 | 11·40 |
| July | 5 | 11·44 | 11·24 | 10·81 | 11·44 |
| | 15 | 11·55 | 11·28 | 10·83 | 11·46 |
| | 25 | 11·55 | 11·28 | 10·95 | 11·49 |
| August | 5 | 11·51 | 11·30 | 11·03 | 11·52 |
| | 15 | 11·51 | 11·30 | 11·07 | 11·52 |
| | 25 | 11·59 | 11·31 | 11·17 | 11·52 |
| September | 5 | 11·62 | 11·32 | 11·21 | 11·57 |
| | 15 | 11·70 | 11·30 | 11·33 | 11·62 |
| | 25 | 11·74 | 11·30 | 11·38 | 11·65 |
| October | 5 | 11·75 | 11·30 | 11·39 | 11·68 |
| | 15 | 11·79 | 11·30 | 11·46 | 11·68 |
| | 25 | 11·77 | 11·31 | 11·51 | 11·65 |
| November | 5 | 11·73 | 11·32 | 11·51 | 11·59 |
| | 15 | 11·66 | 11·31 | 11·37 | 11·54 |
| | 25 | 11·59 | 11·28 | 11·23 | 11·54 |
| December | 5 | 11·56 | 11·28 | 11·11 | 11·55 |
| | 15 | 11·51 | 11·25 | 11·05 | 11·53 |
| | 25 | 11·48 | 11·20 | 11·04 | 11·51 |
| Means | | 11·42 | 11·20 | 10·97 | 11·44 |

Zero of gauge R.L. 396·16, or 10 metres below the original zero of 406·16.

TABLE 76.—ALBERT NILE LEVELS NEAR LAKE NO (in metres).

| Date. | | 1909. | | | 1910. | | | Mean, 1907–1910. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Buffalo Cape. | Lake No. | Feni-kang. | Buffalo Cape. | Lake No. | Feni-kang. | Buffalo Cape. | Lake No. | Feni-kang. |
| January | 5 | 10·93 | 9·18 | 7·83 | 10·96 | 9·31 | 8·26 | 10·91 | 9·14 | 7·56 |
| | 15 | 10·91 | 9·13 | 7·61 | 10·95 | 9·26 | 8·11 | 10·90 | 9·09 | 7·44 |
| | 25 | 10·89 | 9·08 | 7·16 | 10·93 | 9·20 | 7·91 | 10·89 | 9·05 | 7·16 |
| February | 5 | 10·89 | 9·00 | 6·88 | 10·92 | 9·14 | 7·38 | 10·89 | 8·99 | 6·85 |
| | 15 | 10·86 | 8·94 | 6·73 | 10·92 | 9·06 | 6·89 | 10·88 | 8·95 | 6·62 |
| | 25 | 10·86 | 8·88 | 6·61 | 10·91 | 9·01 | 6·56 | 10·87 | 8·91 | 6·44 |
| March | 5 | 10·85 | 8·86 | 6·52 | 10·89 | 8·95 | 6·41 | 10·86 | 8·88 | 6·33 |
| | 15 | 10·85 | 8·83 | 6·46 | 10·89 | 8·89 | 6·16 | 10·86 | 8·84 | 6·19 |
| | 25 | 10·85 | 8·81 | 6·38 | 10·87 | 8·84 | 6·03 | 10·85 | 8·80 | 6·08 |
| April | 5 | 10·85 | 8·81 | 6·33 | 10·86 | 8·80 | 5·88 | 10·84 | 8·78 | 5·95 |
| | 15 | 10·85 | 8·81 | 6·29 | 10·84 | 8·76 | 5·78 | 10·84 | 8·77 | 5·94 |
| | 25 | 10·85 | 8·81 | 6·27 | 10·84 | 8·74 | 5·73 | 10·84 | 8·76 | 5·95 |
| May | 5 | 10·85 | 8·81 | 6·28 | 10·86 | 8·70 | 5·66 | 10·84 | 8·75 | 5·95 |
| | 15 | 10·87 | 8·84 | 6·39 | 10·87 | 8·72 | 5·89 | 10·84 | 8·76 | 6·07 |
| | 25 | 10·87 | 8·88 | 6·49 | 10 88 | 8 76 | 5·90 | 10·85 | 8·80 | 6·17 |
| June | 5 | 10·87 | 8·92 | 6·61 | 10·89 | 8·80 | 6·26 | 10·85 | 8·85 | 6·27 |
| | 15 | 10·88 | 8·96 | 6·74 | 10·90 | 8·83 | 6·43 | 10·86 | 8·89 | 6·41 |
| | 25 | 10·88 | 9·01 | 6·91 | 10·90 | 8·86 | 6·56 | 10·86 | 8·93 | 6·65 |
| July | 5 | 10·88 | 9·04 | 7·04 | 10·90 | 8·89 | 6·72 | 10·87 | 8·96 | 6·81 |
| | 15 | 10·88 | 9·09 | 7·17 | 10·91 | 8·93 | 6·88 | 10·89 | 8·99 | 6·95 |
| | 25 | 10·88 | 9·14 | 7·36 | 10·93 | 8·94 | 7·01 | 10·89 | 9·02 | 7·08 |
| August | 5 | 10·89 | 9·18 | 7·56 | 10·94 | 9·08 | 7·15 | 10·90 | 9·08 | 7·22 |
| | 15 | 10·89 | 9·22 | 7·73 | 10·94 | 9·05 | 7·26 | 10·90 | 9·09 | 7·42 |
| | 25 | 10·89 | 9·26 | 7·91 | 10·96 | 9·04 | 7·36 | 10·91 | 9·12 | 7·57 |
| September | 5 | 10·89 | 9·30 | 8·11 | 10·96 | 9·06 | 7·50 | 10·91 | 9·15 | 7·72 |
| | 15 | 10·89 | 9·33 | 8·26 | 10·96 | 9 08 | 7·60 | 10·92 | 9·17 | 7·83 |
| | 25 | 10·90 | 9·36 | 8·38 | 10·96 | 9 09 | 7·66 | 10·92 | 9·19 | 7·93 |
| October | 5 | 10·92 | 9·38 | 8·46 | 10·96 | 9·09 | 7·76 | 10·93 | 9·20 | 8·02 |
| | 15 | 10·93 | 9·38 | 8·52 | 10·96 | 9·11 | 7·82 | 10·93 | 9·22 | 8·09 |
| | 25 | 10·93 | 9·39 | 8·52 | 10·96 | 9·13 | 7·89 | 10·93 | 9·23 | 8·14 |
| November | 5 | 10·93 | 9·39 | 8·50 | 10·96 | 9·16 | 7·91 | 10·93 | 9·25 | 8·15 |
| | 15 | 10·93 | 9·39 | 8·47 | 10·96 | 9 18 | 7·80 | 10·93 | 9·26 | 8·11 |
| | 25 | 10·94 | 9·39 | 8·43 | 10·96 | 9·18 | 7·84 | 10·94 | 9·26 | 8·11 |
| December | 5 | 10·95 | 9·38 | 8·38 | 10·96 | 9·19 | 7·88 | 10·94 | 9·25 | 8·11 |
| | 15 | 10 95 | 9·37 | 8·37 | 10·96 | 9·19 | 7·92 | 10·94 | 9·23 | 8·10 |
| | 25 | 10·95 | 9·34 | 8·32 | 10·96 | 9·21 | 7·89 | 10·94 | 9·22 | 8·06 |
| Means . | | 10·89 | 9·11 | 7·39 | 10·92 | 9·01 | 7·05 | 10·89 | 9·02 | 7·10 |

To find reduced level of water, add 380·00 metres to each figure.

Extreme range of the river at Buffalo Cape is 0·2 metre.
" " Lake No is 0·8 "
" " Fenikang is 2·8 "

Buffalo Cape is 48 kilometres above Lake No.
Fenikang is 105 " below Lake No.

TABLE 77.—SOBAT RIVER GAUGES AT DOLEIB HILL.
(Ten-day means in metres.)

| Mean Date. | 1909. | 1910. | 1911. | 1912. | Mean, 1906–1911. |
|---|---|---|---|---|---|
| January 5 | 13·58 | 14·09 | 13·57 | 11·90 | 13·15 |
| 15 | 13·25 | 13·96 | 13·20 | 11·67 | 12·81 |
| 25 | 12·62 | 13·61 | 12·49 | 11·48 | 12·36 |
| February 5 | 12·08 | 12·92 | 11·93 | 11·31 | 11·93 |
| 15 | 11·69 | 12·27 | 11·63 | 11·18 | 11·64 |
| 25 | 11·45 | 11·85 | 11·42 | 11·10 | 11·47 |
| March 5 | 11·33 | 11·58 | 11·30 | 11·00 | 11·41 |
| 15 | 11·23 | 11·44 | 11·25 | 10·88 | 11·28 |
| 25 | 11·12 | 11·24 | 11·21 | 10·82 | 11·16 |
| April 5 | 11·30 | 10·99 | 11·14 | 10·74 | 11·12 |
| 15 | 11·58 | 10·90 | 10·96 | 10·79 | 11·15 |
| 25 | 11·68 | 10·88 | 10·92 | 10·65 | 11·12 |
| May 5 | 11·65 | 10·83 | 10·90 | 10·51 | 11·08 |
| 15 | 11·74 | 11·08 | 11·03 | 10·53 | 11·20 |
| 25 | 11·91 | 11·51 | 11·33 | 10·63 | 11·43 |
| June 5 | 12·10 | 11·74 | 11·59 | 10·92 | 11·51 |
| 15 | 12·33 | 11·90 | 11·85 | 11·19 | 11·75 |
| 25 | 12·51 | 12·10 | 12·10 | 11·85 | 12·16 |
| July 5 | 12·65 | 12·33 | 12·39 | 11·95 | 12·39 |
| 15 | 12·80 | 12·49 | 12·53 | 12·16 | 12·57 |
| 25 | 12·96 | 12·64 | 12·66 | 12·40 | 12·72 |
| August 5 | 13·21 | 12·82 | 12·78 | 12·79 | 12·90 |
| 15 | 13·36 | 12·94 | 12·92 | 13·07 | 13·05 |
| 25 | 13·58 | 13·10 | 13·04 | 13·25 | 13·21 |
| September 5 | 13·82 | 13·24 | 13·15 | 13·40 | 13·34 |
| 15 | 13·98 | 13·36 | 13·23 | 13·49 | 13·45 |
| 25 | 14·18 | 13·43 | 13·26 | 13·62 | 13·54 |
| October 5 | 14·34 | 13·52 | 13·32 | 13·66 | 13·63 |
| 15 | 14·34 | 13·59 | 13·37 | 13·67 | 13·68 |
| 25 | 14·29 | 13·67 | 13·42 | 13·66 | 13·71 |
| November 5 | 14·26 | 13·70 | 13·43 | 13·62 | 13·73 |
| 15 | 14·22 | 13·72 | 13·44 | 13·56 | 13·73 |
| 25 | 14·18 | 13·74 | 13·42 | 13·48 | 13·71 |
| December 5 | 14·18 | 13·75 | 13·29 | 13·28 | 13·66 |
| 15 | 14·18 | 13·74 | 12·94 | 12·92 | 13·52 |
| 25 | 14·14 | 13·70 | 12·44 | 12·47 | 13·32 |
| Means | 12·88 | 12·62 | 12·36 | 12·10 | 12·50 |

Zero of gauge R.L. 375·43, or 10 metres below the original zero of 385·43.

TABLE 78.—WHITE NILE GAUGES AT MALAKAL.
(Ten-day means in metres.)

| Mean Date. | 1909. | 1910. | 1911. | 1912. | Mean. |
|---|---|---|---|---|---|
| January 5 | 12·35 | 12·77 | 12·31 | 10·91 | 12·00 |
| 15 | 12·11 | 12·69 | 12·06 | 10·68 | 11·77 |
| 25 | 11·62 | 12·45 | 11·49 | 10·51 | 11·29 |
| February 5 | 11·11 | 11·95 | 10·95 | 10·35 | 10·95 |
| 15 | 10·71 | 11·30 | 10·66 | 10·23 | 10·69 |
| 25 | 10·46 | 10·88 | 10·46 | 10·16 | 10·52 |
| March 5 | 10·38 | 10·61 | 10·35 | 10·06 | 10·45 |
| 15 | 10·29 | 10·48 | 10·30 | 9·95 | 10·33 |
| 25 | 10·19 | 10·30 | 10·25 | 9·89 | 10·43 |
| April 5 | 10·31 | 10·05 | 10·19 | 9·82 | 10·14 |
| 15 | 10·55 | 9·96 | 10·03 | 9·85 | 10·13 |
| 25 | 10·59 | 9·93 | 9·98 | 9·75 | 10·10 |
| May 5 | 10·60 | 9·89 | 9·96 | 9·60 | 10·07 |
| 15 | 10·69 | 10·07 | 10·07 | 9·61 | 10·17 |
| 25 | 10·81 | 10·47 | 10·34 | 9·69 | 10·35 |
| June 5 | 10·99 | 10·68 | 10·56 | 9·94 | 10·56 |
| 15 | 11·17 | 10·81 | 10·79 | 10·05 | 10·77 |
| 25 | 11·37 | 11·00 | 11·00 | 10·53 | 11·00 |
| July 5 | 11·50 | 11·20 | 11·23 | 10·84 | 11·20 |
| 15 | 11·60 | 11·35 | 11·39 | 11·08 | 11·36 |
| 25 | 11·72 | 11·47 | 11·49 | 11·35 | 11·48 |
| August 5 | 11·93 | 11·62 | 11·58 | 11·59 | 11·64 |
| 15 | 12·10 | 11·73 | 11·70 | 11·82 | 11·71 |
| 25 | 12·28 | 11·85 | 11·81 | 11·98 | 11·91 |
| September 5 | 12·51 | 11·99 | 11·91 | 12·10 | 12·05 |
| 15 | 12·68 | 12·10 | 11·98 | 12·19 | 12·15 |
| 25 | 12·87 | 12·17 | 12·00 | 12·28 | 12·24 |
| October 5 | 12·99 | 12·25 | 12·05 | 12·33 | 12·30 |
| 15 | 13·03 | 12·33 | 12·11 | 12·35 | 12·36 |
| 25 | 12·99 | 12·40 | 12·15 | 12·34 | 12·39 |
| November 5 | 12·92 | 12·42 | 12·16 | 12·32 | 12·40 |
| 15 | 12·87 | 12·42 | 12·16 | 12·27 | 12·40 |
| 25 | 12·84 | 12·42 | 12·15 | 12·21 | 12·38 |
| December 5 | 12·82 | 12·45 | 12·08 | 12·07 | 12·35 |
| 15 | 12·82 | 12·44 | 11·82 | 11·78 | 12·26 |
| 25 | 12·82 | 12·43 | 11·41 | 11·40 | 12·11 |
| Means | 11·71 | 11·48 | 11·25 | 11·00 | 11·34 |

The reduced level of the zero of the gauge is 375·00. Malakal is 23 kilometres downstream of the Sobat mouth, and 825 kilometres upstream of Khartoum.

TABLE 79.—BLUE NILE GAUGES AT KAMLIN.
(Five-day means in metres.)

| Date. | | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | 1912. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| January | 1– 5 . | ... | 11·16 | 10·78 | 11·51 | 11·35 | 11·62 | 11·11 | 11·29 |
| | 6–10 . | ... | 11·08 | 10·70 | 11·38 | 11·26 | 11·50 | | 11·18 |
| | 11–15 . | ... | 10·99 | 10·63 | 11·25 | 11·16 | 11·35 | 10·92 | 11·08 |
| | 16–20 . | ... | 10·91 | 10·51 | 11·14 | 11·05 | 11·22 | | 10·96 |
| | 21–25 . | ... | 10·83 | 10·46 | 11·06 | 10·99 | 11·13 | 10·80 | 10·29 |
| | 26–31 . | ... | 10·76 | 10·37 | 11·01 | 10·84 | 11·01 | | 10·76 |
| February | 1– 5 . | ... | 10·69 | 10·34 | 10·96 | 10·76 | 10·91 | 10·66 | 10·73 |
| | 6–10 . | ... | 10·63 | 10·30 | 10·86 | 10·69 | 10·83 | | 10·66 |
| | 11–15 . | ... | 10·57 | 10·28 | 10·76 | 10·60 | 10·77 | 10·54 | 10·60 |
| | 16–20 . | ... | 10·49 | 10·20 | 10·71 | 10·56 | 10·70 | | 10·53 |
| | 21–25 . | ... | 10·43 | 10·17 | 10·67 | 10·51 | 10·61 | 10·38 | 10·48 |
| | 26–end . | ... | 10·41 | 10·13 | 10·62 | 10·44 | 10·57 | | 10·43 |
| March | 1– 5 . | ... | 10·38 | 10·10 | 10·57 | 10·39 | 10·51 | 10·31 | 10·39 |
| | 6–10 . | ... | 10·36 | 10·06 | 10·48 | 10·35 | 10·46 | | 10·34 |
| | 11–15 . | ... | 10·34 | 9·97 | 10·43 | 10·27 | 10·42 | 10·20 | 10·28 |
| | 16–20 . | ... | 10·30 | 9·93 | 10·38 | 10·24 | 10·42 | | 10·25 |
| | 21–25 . | ... | 10·21 | 9·85 | 10·35 | 10·21 | 10·40 | 10·11 | 10·20 |
| | 26–31 . | ... | 10·16 | 9·80 | 10·30 | 10·17 | 10·34 | | 10·15 |
| April | 1– 5 . | ... | 10·10 | 9·77 | 10·32 | 10·15 | 10·28 | 10·01 | 10·12 |
| | 6–10 . | ... | 10·10 | 9·70 | 10·37 | 10·12 | 10·23 | | 10·10 |
| | 11–15 . | ... | 10·11 | 9·71 | 10·53 | 10·08 | 10·18 | 9·93 | 10·12 |
| | 16–20 . | ... | 10·12 | 9·77 | 10·74 | 10·02 | 10·20 | | 10·17 |
| | 21–25 . | ... | 10·35 | 9·68 | 10·71 | 9·99 | 10·17 | 9·90 | 10·18 |
| | 26–30 . | ... | 10·39 | 9·60 | 10·64 | 10·01 | 10·18 | | 10·14 |
| May | 1– 5 . | ... | 10·28 | 9·57 | 10·82 | 10·10 | 10·14 | 9·81 | 10·18 |
| | 6–10 . | ... | 10·20 | 9·62 | 10·90 | 9·98 | 10·10 | | 10·18 |
| | 11–15 . | ... | 10·10 | 9·68 | 10·77 | 10·04 | 10·56 | 9·72 | 10·26 |
| | 16–20 . | ... | 9·99 | 10·11 | 10·64 | 10·26 | 10·80 | | 10·36 |
| | 21–25 . | 10·10 | 9·92 | 9·91 | 10·64 | 10·63 | 11·42 | 9·69 | 10·44 |
| | 26–31 . | 10·10 | 9·95 | 9·78 | 11·57 | 10·95 | 11·02 | | 10·56 |
| June | 1– 5 . | 10·79 | 10·26 | 9·75 | 11·85 | 10·78 | 10·78 | 9·91 | 10·70 |
| | 6–10 . | 10·67 | 10·32 | 9·88 | 12·20 | 10·74 | 10·63 | | 10·74 |
| | 11–15 . | 10·64 | 10·70 | 10·07 | 12·38 | 10·72 | 10·61 | 10·42 | 10·89 |
| | 16–20 . | 10·84 | 11·11 | 10·67 | 12·71 | 11·01 | 11·22 | | 11·26 |
| | 21–25 . | 11·43 | 11·23 | 11·33 | 12·78 | 11·87 | 11·84 | 10·65 | 11·70 |
| | 26–30 . | 11·43 | 11·35 | 11·69 | 13·06 | 11·26 | 11·66 | | 11·74 |

TABLE 79.—BLUE NILE GAUGES AT KAMLIN (*continued*).

| Date. | | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | 1912. | Mean. |
|---|---|---|---|---|---|---|---|---|---|
| July | 1–5 | 11·84 | 11·58 | 11·60 | 12·96 | 11·88 | 11·95 | 11·80 | 11·97 |
| | 6–10 | 12·94 | 12·40 | 11·73 | 13·29 | 12·39 | 12·46 | | 12·55 |
| | 11–15 | 13·89 | 13·00 | 12·80 | 13·70 | 12·91 | 13·12 | 12·88 | 13·24 |
| | 16–20 | 14·12 | 13·40 | 13·80 | 14·92 | 13·01 | 13·53 | | 13·80 |
| | 21–25 | 14·62 | 13·43 | 14·43 | 15·29 | 13·36 | 13·82 | 15·40 | 14·16 |
| | 26–31 | 15·72 | 13·63 | 14·76 | 15·55 | 14·16 | 14·67 | | 14·75 |
| August | 1–5 | 16·90 | 14·26 | 16·72 | 17·07 | 15·10 | 15·75 | 17·03 | 15·97 |
| | 6–10 | 16·70 | 14·92 | 16·30 | 17·51 | 16·92 | 15·83 | | 16·38 |
| | 11–15 | 17·35 | 14·98 | 17·99 | 17·49 | 17·17 | 17·03 | 16·96 | 17·00 |
| | 16–20 | 17·25 | 15·67 | 18·45 | 18·13 | 17·35 | 17·63 | | 17·42 |
| | 21–25 | 17·52 | 16·42 | 18·36 | 17·85 | 17·31 | 17·78 | 17·32 | 17·54 |
| | 26–31 | 17·80 | 16·49 | 18·22 | 18·24 | 17·59 | 17·74 | | 17·68 |
| September | 1–5 | 18·20 | 16·30 | 18·32 | 18·21 | 17·50 | 17·48 | 16·48 | 17·67 |
| | 6–10 | 18·10 | 16·48 | 18·50 | 18·10 | 17·82 | 18·05 | | 17·84 |
| | 11–15 | 18·18 | 16·56 | 18·23 | 17·69 | 17·46 | 17·86 | 16·32 | 17·83 |
| | 16–20 | 18·68 | 16·48 | 17·86 | 17·54 | 17·11 | 17·48 | | 17·53 |
| | 21–25 | 18·32 | 16·02 | 17·74 | 17·63 | 17·25 | 17·26 | 15·39 | 17·37 |
| | 26–30 | 16·53 | 15·35 | 17·76 | 17·61 | 17·25 | 17·23 | | 16·95 |
| October | 1–5 | 16·36 | 14·43 | 17·78 | 17·06 | 17·08 | 16·33 | 13·98 | 16·51 |
| | 6–10 | 16·11 | 13·92 | 17·14 | 16·43 | 16·86 | 15·74 | | 16·03 |
| | 11–15 | 15·53 | 13·71 | 16·13 | 16·25 | 16·97 | 15·40 | 13·18 | 15·66 |
| | 16–20 | 14·61 | 13·69 | 15·61 | 15·53 | 16·58 | 14·59 | | 15·10 |
| | 21–25 | 14·29 | 13·32 | 14·85 | 14·71 | 15·96 | 13·96 | 12·69 | 14·52 |
| | 26–31 | 13·83 | 13·18 | 14·34 | 14·07 | 15·08 | 13·61 | | 14·02 |
| November | 1–5 | 13·34 | 12·77 | 13·89 | 13·37 | 14·68 | 13·44 | 12·24 | 13·58 |
| | 6–10 | 13·02 | 12·47 | 13·61 | 13·20 | 14·52 | 13·44 | | 13·38 |
| | 11–15 | 12·76 | 12·28 | 13·40 | 13·02 | 14·59 | 13·19 | 11·76 | 13·17 |
| | 16–20 | 12·76 | 12·06 | 13·12 | 12·78 | 14·24 | 12·78 | | 12·96 |
| | 21–25 | 12·69 | 11·79 | 12·91 | 12·56 | 14·08 | 12·45 | 11·39 | 12·75 |
| | 26–30 | 12·41 | 11·67 | 12·71 | 12·37 | 13·88 | 12·21 | | 12·54 |
| December | 1–5 | 12·12 | 11·57 | 12·49 | 12·21 | 13·50 | 12·06 | 11·11 | 12·32 |
| | 6–10 | 12·91 | 11·34 | 12·26 | 12·01 | 13·21 | 11·94 | | 12·28 |
| | 11–15 | 12·72 | 11·16 | 12·09 | 11·85 | 12·98 | 11·64 | 10·83 | 12·11 |
| | 16–20 | 12·56 | 11·11 | 11·94 | 11·72 | 12·74 | 11·63 | | 11·95 |
| | 21–25 | 12·45 | 10·95 | 11·80 | 12·58 | 12·38 | 11·42 | 10·65 | 11·76 |
| | 26–31 | 12·31 | 10·87 | 11·76 | 11·43 | 11·88 | 11·29 | | 11·59 |

Zero of gauge R.L. 373·41.

TABLE 80.—KHARTOUM GAUGE READINGS (Reduced Levels).
(Ten-day means, 1905–11, in metres.)

| Mean Date. | | 1905. | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | Mean, 1905–11. | 1912. |
|---|---|---|---|---|---|---|---|---|---|---|
| Jan. | 5 | 376·32 | 376·30 | 376·55 | 376·02 | 376·91 | 377·03 | 376·76 | 376·56 | 376·34 |
| | 15 | 376·10 | 376·18 | 376·32 | 375·79 | 376·78 | 376·89 | 376·59 | 376·38 | 376·09 |
| | 25 | 375·86 | 375·98 | 376·07 | 375·55 | 376·64 | 376·78 | 376·42 | 376·19 | 375·87 |
| Feb. | 5 | 375·57 | 375·69 | 375·86 | 375·37 | 376·47 | 376·67 | 376·18 | 375·97 | 375·68 |
| | 15 | 375·42 | 375·54 | 375·55 | 375·28 | 376·23 | 376·49 | 375·85 | 375·77 | 375·54 |
| | 25 | 375·32 | 375·38 | 375·43 | 375·20 | 375·93 | 376·30 | 375·66 | 375·60 | 375·36 |
| Mar. | 5 | 375·18 | 375·51 | 375·33 | 375·07 | 375·74 | 376·02 | 375·43 | 375·47 | 375·27 |
| | 15 | 375·03 | 375·46 | 375·29 | 374·94 | 375·56 | 375·73 | 375·30 | 375·33 | 375·17 |
| | 25 | 374·95 | 375·36 | 375·21 | 374·84 | 375·46 | 375·58 | 375·21 | 375·23 | 375·01 |
| Apr. | 5 | 374·86 | 375·48 | 375·09 | 374·76 | 375·39 | 375·48 | 375·11 | 375·17 | 374·94 |
| | 15 | 374·79 | 375·31 | 375·07 | 374·75 | 375·58 | 375·26 | 375·06 | 375·12 | 374·85 |
| | 25 | 374·73 | 375·14 | 375·19 | 374·71 | 375·71 | 375·21 | 375·01 | 375·10 | 374·81 |
| May | 5 | 374·65 | 375·12 | 375·25 | 374·66 | 375·87 | 375·16 | 374·91 | 375·09 | 374·77 |
| | 15 | 374·68 | 375·03 | 375·14 | 374·81 | 375·91 | 375·17 | 375·15 | 375·13 | 374·62 |
| | 25 | 374·73 | 374·98 | 375·00 | 374·92 | 376·03 | 375·70 | 375·58 | 375·28 | 374·64 |
| June | 5 | 375·01 | 375·39 | 375·10 | 374·90 | 376·79 | 375·86 | 375·39 | 375·50 | 374·70 |
| | 15 | 375·35 | 375·50 | 375·54 | 375·13 | 377·12 | 375·85 | 375·49 | 375·71 | 375·08 |
| | 25 | 375·92 | 375·93 | 375·96 | 375·88 | 377·42 | 376·04 | 376·05 | 376·17 | 376·05 |
| July | 5 | 376·15 | 376·48 | 375·43 | 376·20 | 377·58 | 376·44 | 376·59 | 376·55 | 376·49 |
| | 15 | 376·69 | 377·70 | 377·31 | 377·17 | 378·24 | 377·22 | 377·52 | 377·41 | 377·05 |
| | 25 | 377·74 | 378·52 | 377·69 | 378·31 | 379·05 | 377·70 | 378·13 | 378·16 | 378·72 |
| Aug. | 5 | 378·59 | 379·84 | 378·30 | 379·85 | 380·20 | 378·48 | 379·23 | 379·21 | 379·79 |
| | 15 | 379·51 | 380·31 | 378·95 | 381·09 | 380·74 | 379·98 | 380·22 | 380·11 | 380·30 |
| | 25 | 379·95 | 380·70 | 379·75 | 381·39 | 381·22 | 380·66 | 380·85 | 380·65 | 380·47 |
| Sept. | 5 | 380·24 | 381·04 | 379·81 | 381·50 | 381·31 | 380·80 | 380·87 | 380·80 | 380·19 |
| | 15 | 380·11 | 381·19 | 379·93 | 381·22 | 381·05 | 380·92 | 380·89 | 380·76 | 379·87 |
| | 25 | 380·06 | 380·65 | 379·49 | 380·90 | 380·90 | 380·63 | 380·31 | 380·42 | 379·42 |
| Oct. | 5 | 379·14 | 380·04 | 378·57 | 380·81 | 380·52 | 380·57 | 379·62 | 379·90 | 378·49 |
| | 15 | 378·19 | 379·33 | 378·11 | 379·99 | 380·03 | 380·35 | 379·14 | 379·31 | 377·83 |
| | 25 | 377·59 | 378·55 | 377·77 | 379·11 | 379·17 | 380·02 | 378·33 | 378·65 | 377·63 |
| Nov. | 5 | 377·37 | 377·94 | 377·40 | 378·42 | 378·55 | 379·12 | 377·96 | 378·11 | 377·32 |
| | 15 | 377·24 | 377·60 | 377·06 | 378·05 | 378·17 | 378·28 | 377·73 | 377·73 | 377·07 |
| | 25 | 377·05 | 377·40 | 376·79 | 377·72 | 377·86 | 377·78 | 377·28 | 377·41 | 376·82 |
| Dec. | 5 | 376·90 | 377·13 | 376·62 | 377·44 | 377·61 | 377·43 | 377·02 | 377·16 | 376·63 |
| | 15 | 376·72 | 376·88 | 376·45 | 377·26 | 377·36 | 377·14 | 376·84 | 376·95 | 376·42 |
| | 25 | 376·46 | 376·71 | 376·26 | 377·10 | 377·15 | 376·93 | 376·59 | 376·74 | 376·32 |
| Means | | 376·67 | 377·15 | 376·71 | 377·11 | 377·73 | 377·44 | 377·12 | 377·13 | 376·69 |

This gauge is on the Blue Nile about 2 kilometres upstream of the White Nile junction. Zero = R.L. 364·82.

TABLE 81.—ATBARA RIVER GAUGES AT KHASHM EL GIRBA.
(Five-day means in metres.)

| Date. | | 1909. | 1910. | 1911. | 1912. |
|---|---|---|---|---|---|
| January | 1– 5 . . | 10·48 | 10·42 | 10·50 | 10·36 |
| | 6–10 . . | 10·45 | 10·38 | 10·46 | |
| | 11–15 . . | 10·43 | 10·35 | 10·42 | 10·29 |
| | 16–20 . . | 10·40 | 10·32 | 10·38 | |
| | 21–25 . . | 10·38 | 10·29 | 10·34 | 10·23 |
| | 26–31 . . | 10·34 | 10·24 | 10·28 | |
| February | 1– 5 . . | 10·29 | 10·18 | 10·24 | 10·16 |
| | 6–10 . . | 10·27 | ... | 10·21 | |
| | 11–15 . . | 10·23 | ... | 10·17 | 10·11 |
| | 16–20 . . | 10·19 | ... | 10·13 | |
| | 21–25 . . | 10·15 | ... | 10·11 | 10·07 |
| | 26–end . . | 10·08 | ... | 10·08 | |
| March | 1– 5 . . | 10·04 | ... | 10·05 | 10·03 |
| | 6–10 . . | 10·02 | ... | 10·02 | |
| | 11–15 . . | 10·00 | | | |
| | 16–20 . . | 9·96 | | | |
| | 21–25 . . | 9·94 | | | |
| | 26–31 . . | 9·91 | | | |
| April | 1– 5 . . | 9·87 | | | |
| | 6–10 . . | 9·85 | | | |
| | 11–15 . . | 9·83 | | | |
| | 16–20 . . | 10·20 | | | |
| | 21–25 . . | 10·27 | | | |
| | 26–30 . . | 10·24 | | | |
| May | 1– 5 . . | 10·22 | | | |
| | 6–10 . . | 10·26 | | | |
| | 11–15 . . | 10·35 | | | |
| | 16–20 . . | 10·12 | | | |
| | 21–25 . . | | | | |
| | 26–31 . . | | | | |
| June | 1– 5 . . | 11·33 | 10·45 | 10·38 | |
| | 6–10 . . | 11·92 | 10·37 | 10·23 | |
| | 11–15 . . | 11·83 | 10·39 | 10·64 | |
| | 16–20 . . | 11·75 | 10·35 | 11·23 | |
| | 21–25 . . | 11·99 | 11·11 | 11·21 | 14·79 |
| | 26–30 . . | 12·31 | 11·63 | 11·15 | |

Table 81 (*continued*).

| Date. | | 1909. | 1910. | 1911. | 1912. |
|---|---|---|---|---|---|
| July | 1– 5 | 12·12 | 11·61 | 11·52 | 12·32 |
| | 6–10 | 12·33 | 12·08 | 11·75 | |
| | 11–15 | 12·86 | 11·89 | 11·88 | 12·29 |
| | 16–20 | 12·42 | 12·22 | 12·16 | |
| | 21–25 | 12·93 | 13·13 | 12·84 | 13·65 |
| | 26–31 | 14·16 | 13·63 | 13·22 | |
| August | 1– 5 | 14·17 | 13·76 | 13·05 | 14·54 |
| | 6–10 | 14·23 | 14·98 | 13·89 | |
| | 11–15 | 14·56 | 14·60 | 14·52 | 14·28 |
| | 16–20 | 15·10 | 14·96 | 14·83 | |
| | 21–25 | 14·69 | 14·94 | 14·30 | 14·23 |
| | 26–31 | 15·10 | 15·43 | 14·06 | |
| September | 1– 5 | 14·53 | 14·96 | 14·34 | 13·98 |
| | 6–10 | 13·98 | 14·40 | 14·66 | |
| | 11–15 | 14·00 | 13·87 | 14·36 | 13·33 |
| | 16–20 | 13·60 | 13·71 | 13·46 | |
| | 21–25 | 13·68 | 13·84 | 12·87 | 12·20 |
| | 26–30 | 12·90 | 13·36 | 12·50 | |
| October | 1– 5 | 12·53 | 13·06 | 12·17 | 11·56 |
| | 6–10 | 12·35 | 12·94 | 12·06 | |
| | 11–15 | 12·18 | 12·90 | 11·82 | |
| | 16–20 | 11·92 | 12·52 | 11·57 | |
| | 21–25 | 11·63 | 12·22 | 11·41 | |
| | 26–31 | 11·40 | 11·84 | 11·34 | |
| November | 1– 5 | 11·26 | 11·60 | 11·58 | |
| | 6–10 | 11·15 | 11·48 | 11·49 | |
| | 11–15 | 11·06 | 11·31 | 11·23 | |
| | 16–20 | 10·95 | 11·17 | 11·05 | |
| | 21–25 | 10·85 | 11·04 | 10·87 | |
| | 26–30 | 10·79 | 10·92 | 10·75 | |
| December | 1– 5 | 10·73 | 10·83 | 10·70 | |
| | 6–10 | 10·65 | 10·76 | 10·66 | |
| | 11–15 | 10·61 | 10·69 | 10·62 | |
| | 16–20 | 10·56 | 10·62 | 10·56 | |
| | 21–25 | 10·51 | 10·58 | 10·51 | |
| | 26–31 | 10·45 | 10·53 | 10·46 | |

TABLE 82.—MAIN NILE GAUGES AT WADI HALFA.
(Five-day means, in metres).

| Date | | 1892. | 1893. | 1894. | 1898. | 1899. | 15 Years. |
|---|---|---|---|---|---|---|---|
| January | 1– 5 | 3·37 | 3·96 | 3·42 | 3·06 | 3·62 | 3·25 |
| | 6–10 | 3·22 | 3·89 | 3·35 | 2·96 | 3·50 | 3·15 |
| | 11–15 | 3·15 | 3·82 | 3·31 | 2·92 | 3·48 | 3·07 |
| | 16–20 | 3·04 | 3·77 | 3·26 | 2·87 | 3·37 | 2·99 |
| | 21–25 | 2·93 | 3·70 | 3·18 | 2·83 | 3·33 | 2·91 |
| | 26–31 | 2·83 | 3·67 | 3·07 | 2·74 | 3·29 | 2·81 |
| February | 1 –5 | 2·69 | 3·59 | 2·95 | 2·71 | 3·25 | 2·71 |
| | 6–10 | 2·55 | 3·47 | 2·82 | 2·62 | 3·20 | 2·62 |
| | 11–15 | 2·40 | 3·46 | 2·70 | 2·47 | 3·15 | 2·53 |
| | 16–20 | 2·24 | 3·41 | 2·56 | 2·37 | 3·11 | 2·46 |
| | 21–25 | 2·10 | 3·35 | 2·42 | 2·21 | 3·05 | 2·36 |
| | 26–end | 1·97 | 3·29 | 2·32 | 2·05 | 3·04 | 2·28 |
| March | 1– 5 | 1·86 | 3·26 | 2·24 | 1·96 | 2·99 | 2·21 |
| | 6–10 | 1·78 | 3·20 | 2·12 | 1·89 | 2·91 | 2·13 |
| | 11–15 | 1·67 | 3·23 | 2·02 | 1·79 | 2·84 | 2·04 |
| | 16–20 | 1·55 | 3·18 | 1·92 | 1·74 | 2·76 | 1·97 |
| | 21–25 | 1·51 | 3·18 | 1·84 | 1·65 | 2·67 | 1·90 |
| | 26–31 | 1·40 | 3·16 | 1·78 | 1·59 | 2·56 | 1·83 |
| April | 1– 5 | 1·31 | 3·17 | 1·73 | 1·51 | 2·42 | 1·77 |
| | 6–10 | 1·23 | 3·13 | 1·70 | 1·47 | 2·30 | 1·70 |
| | 11–15 | 1·17 | 3·00 | 1·67 | 1·45 | 2·16 | 1·65 |
| | 16–20 | 1·13 | 2·86 | 1·63 | 1·38 | 2·09 | 1·61 |
| | 21–25 | 1·06 | 2·62 | 1·59 | 1·35 | 2·02 | 1·54 |
| | 26–30 | 1·00 | 2·40 | 1·53 | 1·29 | 1·93 | 1·49 |
| May | 1– 5 | 0·97 | 2·24 | 1·52 | 1·25 | 1·87 | 1·45 |
| | 6–10 | 0·95 | 2·03 | 1·54 | 1·26 | 1·81 | 1·42 |
| | 11–15 | 0·93 | 1·91 | 1·61 | 1·23 | 1·76 | 1·43 |
| | 16–20 | 0·97 | 1·82 | 1·66 | 1·19 | 1·67 | 1·43 |
| | 21–25 | 0·88 | 1·74 | 1·66 | 1·17 | 1·53 | 1·41 |
| | 26–31 | 0·84 | 1·70 | 1·67 | 1·16 | 1·47 | 1·40 |
| June | 1– 5 | 0·88 | 1·62 | 1·66 | 1·18 | 1·52 | 1·42 |
| | 6–10 | 0·94 | 1·56 | 1·57 | 1·11 | 1·54 | 1·47 |
| | 11–15 | 0·96 | 1·54 | 1·57 | 1·12 | 1·65 | 1·55 |
| | 16–20 | 1·06 | 1·60 | 1·76 | 1·11 | 1·85 | 1·69 |
| | 21–25 | 1·30 | 1·68 | 2·49 | 1·38 | 1·87 | 1·92 |
| | 26–30 | 1·56 | 1·78 | 3·05 | 2·09 | 1·90 | 2·11 |

TABLE 82 (*continued*).

| Date. | | 1892. | 1893. | 1894. | 1898. | 1899. | 15 Years. |
|---|---|---|---|---|---|---|---|
| July | 1– 5 | 1·76 | 2·00 | 3·06 | 2·14 | 2·05 | 2·31 |
| | 6–10 | 2·44 | 2·24 | 3·14 | 2·13 | 2·28 | 2·57 |
| | 11–15 | 2·79 | 2·57 | 3·54 | 2·35 | 2·96 | 2·93 |
| | 16–20 | 3·55 | 3·22 | 4·48 | 2·94 | 3·65 | 3·55 |
| | 21–25 | 4·52 | 3·90 | 5·12 | 3·42 | 3·90 | 4·12 |
| | 26–31 | 5·66 | 5·46 | 5·59 | 3·86 | 4·19 | 4·86 |
| August | 1– 5 | 6·74 | 6·26 | 6·50 | 5·84 | 4·53 | 5·73 |
| | 6–10 | 7·04 | 7·12 | 7·59 | 7·60 | 5·55 | 6·63 |
| | 11–15 | 7·08 | 7·20 | 7·99 | 7·61 | 6·18 | 7·11 |
| | 16–20 | 7·60 | 7·58 | 8·17 | 8·02 | 6·06 | 7·47 |
| | 21–25 | 8·53 | 7·70 | 8·84 | 8·44 | 6·46 | 7·80 |
| | 26–31 | 8·59 | 7·59 | 8·93 | 8·60 | 6·78 | 7·90 |
| September | 1– 5 | 8·70 | 7·46 | 8·74 | 8·46 | 6·86 | 7·94 |
| | 6–10 | 8·95 | 7·60 | 8·57 | 8·38 | 6·61 | 7·91 |
| | 11–15 | 9·00 | 7·80 | 8·79 | 8·21 | 6·44 | 7·89 |
| | 16–20 | 8·99 | 7·64 | 8·83 | 8·14 | 6·48 | 7·83 |
| | 21–25 | 8·86 | 7·78 | 8·60 | 7·93 | 6·27 | 7·69 |
| | 26–30 | 8·68 | 7·60 | 8·55 | 7·72 | 5·95 | 7·44 |
| October | 1– 5 | 8·44 | 7·46 | 8·46 | 7·67 | 5·66 | 7·17 |
| | 6–10 | 8·05 | 7·58 | 8·32 | 7·40 | 5·16 | 6·91 |
| | 11–15 | 7·75 | 7·33 | 8·06 | 7·06 | 4·72 | 6·60 |
| | 16–20 | 7·45 | 6·87 | 7·75 | 6·79 | 4·33 | 6·27 |
| | 21–25 | 7·11 | 6·41 | 7·31 | 6·56 | 4·00 | 5·91 |
| | 26–31 | 6·66 | 6·01 | 6·75 | 6·14 | 3·73 | 5·54 |
| November | 1– 5 | 6·08 | 5·70 | 6·30 | 5·65 | 3·47 | 5·19 |
| | 6–10 | 5·57 | 5·28 | 5·83 | 5·31 | 3·22 | 4·85 |
| | 11–15 | 5·28 | 4·95 | 5·48 | 5·02 | 3·09 | 4·59 |
| | 16–20 | 5·01 | 4·72 | 5·22 | 4·83 | 2·96 | 4·38 |
| | 21–25 | 4·78 | 4·54 | 5·05 | 4·58 | 2·87 | 4·23 |
| | 26–30 | 4·57 | 4·32 | 4·84 | 4·46 | 2·76 | 4·08 |
| December | 1– 5 | 4·45 | 4·10 | 4·68 | 4·32 | 2·64 | 3·92 |
| | 6–10 | 4·30 | 3·98 | 4·57 | 4·24 | 2·52 | 3·80 |
| | 11–15 | 4·25 | 3·85 | 4·47 | 4·20 | 2·39 | 3·70 |
| | 16–20 | 4·12 | 3·73 | 4·43 | 4·04 | 2·26 | 3·58 |
| | 21–25 | 4·08 | 3·64 | 4·33 | 3·88 | 2·10 | 3·46 |
| | 26–31 | 4·02 | 3·53 | 4·18 | 3·73 | 1·98 | 3·35 |
| Yearly Mean | | 3·93 | 4·22 | 4·31 | 3·81 | 3·37 | 3·77 |
| Max. | | 9·04 | 7·90 | 8·96 | 8·72 | 6·92 | 8·20 |
| Min. | | 0·83 | 1·52 | 1·52 | 1·09 | 1·46 | 1·30 |

Zero of gauge, 116·7$^{m}$ above mean sea-level at Alexandria.

Table 83.—Main Nile Gauges at Wadi Halfa.
(Five-day means, in metres.)

| Date. | | 1907. | 1908. | 1911. | 1912. |
|---|---|---|---|---|---|
| January | 1– 5 | 2·83 | 2·53 | 3·25 | 3·01 |
| | 6–10 | 2·80 | 2·51 | 3·20 | 2·93 |
| | 11–15 | 2·78 | 2·43 | 3·16 | 2·83 |
| | 16–20 | 2·60 | 2·34 | 3·08 | 2·72 |
| | 21–25 | 2·54 | 2·26 | 3·01 | 2·59 |
| | 26–31 | 2·46 | 2·11 | 2·95 | 2·47 |
| February | 1– 5 | 2·37 | 2·01 | 2·89 | 2·35 |
| | 6–10 | 2·28 | 1·93 | 2·79 | 2·25 |
| | 11–15 | 2·20 | 1·81 | 2·69 | 2·16 |
| | 16–20 | 2·09 | 1·72 | 2·64 | 2·07 |
| | 21–25 | 2·00 | 1·63 | 2·51 | 1·96 |
| | 26–end | 1·92 | 1·62 | 2·38 | 1·89 |
| March | 1– 5 | 1·83 | 1·58 | 2·32 | 1·80 |
| | 6–10 | 1·72 | 1·56 | 2·20 | 1·68 |
| | 11–15 | 1·63 | 1·51 | 2·14 | 1·63 |
| | 16–20 | 1·56 | 1·46 | 2·01 | 1·61 |
| | 21–25 | 1·55 | 1·43 | 1·89 | 1·57 |
| | 26–31 | 1·55 | 1·36 | 1·80 | 1·52 |
| April | 1– 5 | 1·54 | 1·29 | 1·75 | 1·47 |
| | 6–10 | 1·53 | 1·25 | 1·71 | 1·39 |
| | 11–15 | 1·53 | 1·22 | 1·67 | 1·34 |
| | 16–20 | 1·51 | 1·18 | 1·61 | 1·29 |
| | 21–25 | 1·47 | 1·16 | 1·58 | 1·28 |
| | 26–30 | 1·40 | 1·17 | 1·54 | 1·24 |
| May | 1– 5 | 1·40 | 1·14 | 1·49 | 1·22 |
| | 6–10 | 1·42 | 1·09 | 1·50 | 1·15 |
| | 11–15 | 1·54 | 1·08 | 1·50 | 1·13 |
| | 16–20 | 1·55 | 1·08 | 1·48 | 1·14 |
| | 21–25 | 1·57 | 1·07 | 1·44 | 1·11 |
| | 26–29 | 1·52 | 1·07 | 1·47 | 1·06 |
| June | 1– 5 | 1·51 | 1·17 | 1·61 | 1·00 |
| | 6–10 | 1·42 | 1·25 | 1·82 | 0·99 |
| | 11–15 | 1·35 | 1·27 | 1·96 | 1·03 |
| | 16–20 | 1·43 | 1·25 | 1·85 | 1·04 |
| | 21–25 | 1·53 | 1·22 | 1·82 | 1·08 |
| | 26–30 | 1·57 | 1·28 | 1·83 | 1·15 |

TABLE 83 (*continued*).

| Date. | | 1907. | 1908. | 1911. | 1912. |
|---|---|---|---|---|---|
| July | 1– 5 | 1·77 | 1·36 | 1·93 | 1·29 |
| | 6–10 | 1·99 | 1·69 | 2·28 | 1·71 |
| | 11–15 | 2·14 | 2·27 | 2·46 | 2·30 |
| | 16–20 | 2·30 | 2·56 | 2·68 | 2·88 |
| | 21–25 | 3·09 | 3·03 | 3·13 | 3·15 |
| | 26–31 | 3·79 | 4·02 | 3·83 | 3·69 |
| August | 1– 5 | 4·71 | 4·77 | 4·58 | 5·55 |
| | 6–10 | 4·66 | 5·51 | 5 12 | 6·55 |
| | 11–15 | 4·84 | 7·41 | 5·68 | 7·03 |
| | 16–20 | 5·43 | 8·14 | 6·30 | 7·55 |
| | 21–25 | 6·08 | 8·39 | 7·47 | 7·42 |
| | 26–31 | 6·45 | 8·21 | 7·64 | 7·44 |
| September | 1– 5 | 7·02 | 8·22 | 7·67 | 7·42 |
| | 6–10 | 6·84 | 8·44 | 7·64 | 7·47 |
| | 11–15 | 6·79 | 8·43 | 8·04 | 7·13 |
| | 16–20 | 6·80 | 8·26 | 8·00 | 6·85 |
| | 21–25 | 6·77 | 8·13 | 7·74 | 6·58 |
| | 26–30 | 6·50 | 7·86 | 7·40 | 6·53 |
| October | 1– 5 | 6·08 | 7·66 | 7·00 | 6·17 |
| | 6–10 | 5·64 | 7·56 | 6·51 | 5·70 |
| | 11–15 | 5·12 | 7·46 | 6·14 | 5·22 |
| | 16–20 | 4·67 | 6·96 | 5·87 | 4·78 |
| | 21–25 | 4·44 | 6·40 | 5·64 | 4·40 |
| | 26–31 | 4·27 | 5·89 | 5·20 | 4·06 |
| November | 1– 5 | 4·07 | 5·31 | 4·72 | 3·81 |
| | 6–10 | 3·92 | 4·86 | 4·41 | 3·71 |
| | 11–15 | 3·76 | 4·51 | 4·23 | 3·57 |
| | 16–20 | 3·54 | 4·25 | 4·18 | 3·49 |
| | 21–25 | 3·32 | 4·07 | 4·11 | 3·36 |
| | 26–30 | 3·22 | 3·83 | 3·96 | 3·22 |
| December | 1– 5 | 3·07 | 3·73 | 3·71 | 3·11 |
| | 6–10 | 2·97 | 3·56 | 3·56 | 2·96 |
| | 11–15 | 2·86 | 3·43 | 3·45 | 2·87 |
| | 16–20 | 2·84 | 3·33 | 3·31 | 2·79 |
| | 21–25 | 2·73 | 3·25 | 3·25 | 2·69 |
| | 26–31 | 2·66 | 3·15 | 3·14 | 2·61 |

Zero of gauge R.L. 116·70.

TABLE 84.—ASWAN (ELEPHANTINE) GAUGE.
(R.L. in metres. Referred to mean sea-level.)

| Date. | | 1892. | 1907. | 1908. | 1912. | Mean, 1873–1902. |
|---|---|---|---|---|---|---|
| January | 1– 5 . | 87·72 | 86·75 | 86·38 | 86·68 | 87·59 |
| | 6–10 . | 87·56 | 86·65 | 86·29 | 86·58 | 87·48 |
| | 11–15 . | 87·42 | 86·59 | 86·19 | 86·47 | 87·37 |
| | 16–20 . | 87·35 | 86·54 | 86·07 | 86·47 | 87·25 |
| | 21–25 . | 87·25 | 86·50 | 85·93 | 86·20 | 87·14 |
| | 26–31 . | 87·07 | 86·41 | 85·76 | 86·20 | 87·02 |
| February | 1– 5 . | 86·95 | 86·25 | 85·58 | 86·16 | 86·91 |
| | 6–10 . | 86·77 | 86·13 | 85·38 | 85·94 | 86·80 |
| | 11–15 . | 86·63 | 86·01 | 85·25 | 85·79 | 86·68 |
| | 16–20 . | 86·45 | 85·89 | 85·17 | 85·68 | 86·56 |
| | 21–25 . | 86·29 | 85·75 | 85·21 | 85·54 | 86·46 |
| | 26–end . | 86·11 | 85·65 | 85·10 | 85·44 | 86·37 |
| March | 1– 5 . | 85·95 | 85·53 | 84·99 | 85·40 | 86·27 |
| | 6–10 . | 85·82 | 85·37 | 84·90 | 85·32 | 86·17 |
| | 11–15 . | 85·72 | 85·18 | 84·86 | 85·22 | 86·07 |
| | 16–20 . | 85·56 | 85·01 | 84·78 | 85·00 | 85·96 |
| | 21–25 . | 85·40 | 84·89 | 84·70 | 84·90 | 85·86 |
| | 26–31 . | 85·31 | 84·90 | 84·64 | 84·90 | 85·74 |
| April | 1– 5 . | 85·21 | 84·94 | 84·65 | 84·90 | 85·64 |
| | 6–10 . | 85·07 | 84·97 | 84·65 | 84·90 | 85·55 |
| | 11–15 . | 84·99 | 84·98 | 84·65 | 84·88 | 85·48 |
| | 16–20 . | 84·90 | 84·96 | 84·65 | 84·80 | 85·41 |
| | 21–25 . | 84·84 | 84·95 | 84·65 | 84·80 | 85·35 |
| | 26–30 . | 84·73 | 84·95 | 84·65 | 84·80 | 85·27 |
| May | 1– 5 . | 84·67 | 84·95 | 84·60 | 84·80 | 85·22 |
| | 6–10 . | 84·66 | 84·95 | 84·53 | 84·80 | 85·16 |
| | 11–15 . | 84·63 | 84·97 | 84·50 | 84·80 | 85·13 |
| | 16–20 . | 84·55 | 84·96 | 84·50 | 84·80 | 85·09 |
| | 21–25 . | 84·57 | 84·96 | 84·50 | 84·80 | 85·08 |
| | 26–31 . | 84·48 | 84·96 | 84·50 | 84·80 | 85·09 |
| June | 1– 5 . | 84·38 | 84·96 | 84·50 | 84·84 | 85·11 |
| | 6–10 . | 84·42 | 84·96 | 84·50 | 84·85 | 85·15 |
| | 11–15 . | 84·51 | 84·96 | 84·53 | 84·90 | 85·24 |
| | 16–20 . | 84·56 | 84·96 | 84·65 | 84·82 | 85·37 |
| | 21–25 . | 84·74 | 85·21 | 84·70 | 85·00 | 85·53 |
| | 26–30 . | 85·04 | 85·20 | 84·84 | 85·00 | 85·86 |

TABLE 84 (*continued*).

| Date. | | 1892. | 1907. | 1908. | 1912. | Mean, 1873–1902. |
|---|---|---|---|---|---|---|
| July | 1– 5 . | 85·43 | 85·34 | 84·98 | 85·13 | 86·15 |
| | 6–10 . | 85·76 | 85·56 | 85·18 | 85·32 | 86·49 |
| | 11–15 . | 86·46 | 85·79 | 85·47 | 85·62 | 86·90 |
| | 16–20 . | 87·00 | 86·13 | 85·99 | 86·35 | 87·51 |
| | 21–25 . | 88·33 | 86·56 | 86·12 | 86·84 | 88·28 |
| | 26–31 . | 89·64 | 87·67 | 87·37 | 87·13 | 89·25 |
| August | 1– 5 . | 91·17 | 88·50 | 88·65 | 88·82 | 90·16 |
| | 6–10 . | 91·57 | 89·03 | 89·17 | 90·62 | 91·14 |
| | 11–15 . | 91·67 | 88·88 | 91·10 | 91·16 | 91·80 |
| | 16–20 . | 92·06 | 89·53 | 92·48 | 91·96 | 92·18 |
| | 21–25 . | 93·00 | 90·20 | 93·02 | 91·92 | 92·46 |
| | 26–31 . | 93·34 | 90·83 | 92·94 | 91·86 | 92·69 |
| September | 1– 5 . | 93·48 | 91·44 | 92·92 | 91·86 | 92·82 |
| | 6–10 . | 93·72 | 91·23 | 93·14 | 91·89 | 92·81 |
| | 11–15 . | 93·79 | 91·16 | 93·21 | 91·62 | 92·78 |
| | 16–20 . | 93·78 | 91·14 | 93·11 | 91·27 | 92·70 |
| | 21–25 . | 93·74 | 91·18 | 92·94 | 90·98 | 92·60 |
| | 26–30 . | 93·49 | 90·94 | 92·72 | 90·90 | 92·38 |
| October | 1– 5 . | 93·27 | 90·57 | 92·37 | 90·65 | 92·04 |
| | 6–10 . | 92·93 | 90·21 | 92·17 | 90·17 | 91·72 |
| | 11–15 . | 92·53 | 89·67 | 92·07 | 89·68 | 91·40 |
| | 16–20 . | 92·26 | 89·17 | 91·72 | 89·12 | 91·03 |
| | 21–25 . | 91·95 | 88·79 | 91·05 | 88·06 | 90·69 |
| | 26–31 . | 91·50 | 88·51 | 90·53 | 87·61 | 90·26 |
| November | 1– 5 . | 90·95 | 88·35 | 89·95 | 87·52 | 89·35 |
| | 6–10 . | 90·49 | 87·99 | 89·51 | 87·31 | 89·48 |
| | 11–15 . | 90·06 | 87·74 | 89·08 | 87·14 | 89·16 |
| | 16–20 . | 89·76 | 87·56 | 88·76 | 87·00 | 88·91 |
| | 21–25 . | 89·49 | 87·38 | 88·54 | 87·00 | 88·71 |
| | 26–30 . | 89·21 | 86 88 | 88·25 | 87·00 | 88·53 |
| December | 1– 5 . | 88·98 | 86·42 | 87·82 | 87·00 | 88·36 |
| | 6–10 . | 88·81 | 86·54 | 87·59 | 87·00 | 88·21 |
| | 11–15 . | 88·66 | 86·53 | 87·42 | 86·91 | 88·07 |
| | 16–20 . | 88·54 | 86·54 | 87·27 | 86·81 | 87·93 |
| | 21–25 . | 88·43 | 86·54 | 87·15 | 86·71 | 87·80 |
| | 26–31 . | 88·32 | 86·50 | 87·10 | 86·60 | 87·64 |

TABLE 85.—ASSIUT GAUGE READINGS.
(Five-day means. R.L. in metres above mean sea.)

| Date. | | 1892. | Assiut Barrage (upstream). | | | Assiut Barrage (downstream). | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1907. | 1908. | 1912. | 1907. | 1908. | 1912. |
| January | 1– 5 . | 47·76 | 47·62 | 47·54 | 47·58 | 47·61 | 47·32 | 47·53 |
| | 6–10 . | 47·62 | 47·56 | 47·48 | 47·54 | 47·55 | 47·22 | 47·50 |
| | 11–15 . | 47·48 | 47·47 | 47·49 | 47·47 | 47·46 | 47·15 | 47·43 |
| | 16–20 . | 47·38 | 47·42 | 47·50 | 47·31 | 47·41 | 47·24 | 47·26 |
| | 21–25 . | 47·31 | 47·38 | 47·50 | 47·48 | 47·37 | 46·95 | 47·08 |
| | 26–31 . | 47·22 | 47·35 | 47·50 | 47·81 | 47·33 | 46·77 | 46·99 |
| February | 1– 5 . | 47·10 | 47·30 | 47·50 | 48·08 | 47·24 | 46·64 | 46·89 |
| | 6–10 . | 46·99 | 47·23 | 47·50 | 48·03 | 47·16 | 46·48 | 46·80 |
| | 11–15 . | 46·86 | 47·50 | 47·50 | 48·26 | 46·86 | 46·15 | 46·45 |
| | 16–20 . | 46·70 | 47·50 | 47·50 | 48·26 | 46·86 | 46·15 | 46·45 |
| | 21–25 . | 46·55 | 47·50 | 47·50 | 48·26 | 46·68 | 46·04 | 46·34 |
| | 25–end . | 46·41 | 47·50 | 47·55 | 48·21 | 46·60 | 46·02 | 46·23 |
| March | 1– 5 . | 46·26 | 47·56 | 47·63 | 48·13 | 46·50 | 45·95 | 46·15 |
| | 6–10 . | 46·12 | 47·50 | 47·58 | 48·08 | 46·37 | 45·86 | 46·10 |
| | 11–15 . | 45·99 | 47·50 | 47·55 | 48·02 | 46·22 | 45·77 | 46·03 |
| | 16–20 . | 45·87 | 47·48 | 47·55 | 47·93 | 46·06 | 45·72 | 45·97 |
| | 21–25 . | 45·73 | 47·40 | 47·52 | 47·74 | 45·90 | 45·67 | 45·85 |
| | 26–31 . | 45·59 | 47·40 | 47·39 | 47·54 | 45·74 | 45·62 | 45·76 |
| April | 1– 5 . | 45·50 | 47·40 | 47·34 | 47·25 | 45·70 | 45·53 | 45·76 |
| | 6–10 . | 45·40 | 47·31 | 47·22 | 47·19 | 45·78 | 45·55 | 45·75 |
| | 11–15 . | 45·30 | 47·04 | 47·15 | 47·17 | 45·83 | 45·55 | 45·75 |
| | 16–20 . | 45·18 | 47·11 | 47·07 | 47·15 | 45·78 | 45·55 | 45·74 |
| | 21–25 . | 45·07 | 47·20 | 47·07 | 47·09 | 45·75 | 45·55 | 45·70 |
| | 26–30 . | 45·00 | 47·21 | 47·07 | 47·09 | 45·74 | 45·54 | 45·67 |
| May | 1– 5 . | 44·92 | 47·25 | 47·05 | 47·08 | 45·74 | 45·53 | 45·65 |
| | 6–10 . | 44·85 | 47·25 | 47·13 | 47·09 | 45·73 | 45·50 | 45·65 |
| | 11–15 . | 44·80 | 47·25 | 47·30 | 47·03 | 45·72 | 45·47 | 45·65 |
| | 16–20 . | 44·73 | 47·25 | 47·30 | 46·98 | 45·71 | 45·45 | 45·64 |
| | 21–25 . | 44·67 | 47·25 | 47·30 | 47·02 | 45·71 | 45·45 | 45·65 |
| | 26–31 . | 44·65 | 47·35 | 47·30 | 47·01 | 45·69 | 45·45 | 45·63 |
| June | 1 –5 . | 44·62 | 47·23 | 46·92 | 46·97 | 45·71 | 45·47 | 45·61 |
| | 6–10 . | 44·55 | 47·21 | 46·86 | 46·96 | 45·65 | 45·44 | 45·62 |
| | 11–15 . | 44·54 | 47·13 | 46·85 | 46·96 | 45·68 | 45·45 | 45·63 |
| | 16–20 . | 44·56 | 47·15 | 46·89 | 46·97 | 45·67 | 45·45 | 45·64 |
| | 21–25 . | 44·60 | 47·15 | 46·91 | 46·99 | 45·66 | 45·48 | 45·65 |
| | 26–30 . | 44·64 | 47·23 | 46·90 | 47·06 | 45·78 | 45·50 | 45·69 |

TABLE 85 (*continued*).

| Date. | | 1892. | Assiut Barrage (upstream). | | | Assiut Barrage (downstream). | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1907. | 1908. | 1912. | 1907. | 1908. | 1912. |
| July | 1– 5 | 44·78 | 47·26 | 47·06 | 47·12 | 45·85 | 45·57 | 45·73 |
| | 6–10 | 45·10 | 47·30 | 47·30 | 47·19 | 45·94 | 45·63 | 45·78 |
| | 11–15 | 45·36 | 47·42 | 47·37 | 47·31 | 46·11 | 45·73 | 45·86 |
| | 16–20 | 46·00 | 47·49 | 47·57 | 47·58 | 46·31 | 45·89 | 46·01 |
| | 21–25 | 46·62 | 47·56 | 47·91 | 48·13 | 46·57 | 46·32 | 46·43 |
| | 26–31 | 47·98 | 47·74 | 48·03 | 48·52 | 47·02 | 46·52 | 46·98 |
| August | 1– 5 | 49·47 | 48·46 | 49·09 | 48·98 | 47·86 | 47·50 | 47·26 |
| | 6–10 | 50·64 | 49·60 | 49·53 | 50·13 | 48·39 | 48·55 | 48·93 |
| | 11–15 | 50·97 | 50·24 | 49·95 | 50·04 | 48·74 | 49·30 | 50·29 |
| | 16–20 | 50·65 | 50·19 | 50·86 | 51·78 | 48·70 | 50·84 | 50·58 |
| | 21–25 | 51·25 | 50·56 | 51·61 | 51·35 | 49·19 | 51·59 | 50·84 |
| | 26–31 | 51·97 | 51·00 | 51·82 | 51·51 | 48·71 | 51·79 | 50·72 |
| September | 1– 5 | 52·13 | 51·46 | 51·82 | 51·79 | 50·40 | 51·79 | 50·74 |
| | 6–10 | 52·40 | 51·50 | 51·88 | 51·84 | 50·53 | 51·87 | 50·74 |
| | 11–15 | 52·84 | 51·50 | 53·08 | 51·82 | 50·37 | 52·07 | 50·83 |
| | 16–20 | 53·13 | 51·50 | 52·37 | 51·69 | 50·36 | 52·37 | 50·63 |
| | 21–25 | 53·20 | 51·50 | 52·49 | 51·53 | 50·46 | 52·48 | 50·47 |
| | 26–30 | 53·23 | 51·50 | 52·46 | 51·39 | 50·40 | 52·45 | 50·33 |
| October | 1– 5 | 53·11 | 51·35 | 52·12 | 51·32 | 50·22 | 52·11 | 50·23 |
| | 6–10 | 52·91 | 51·19 | 51·91 | 51·13 | 50·03 | 51·89 | 50·03 |
| | 11–15 | 52·70 | 50·76 | 52·04 | 50·89 | 49·74 | 52·01 | 49·73 |
| | 16–20 | 52·49 | 50·66 | 52·07 | 50·76 | 49·35 | 52·05 | 49·56 |
| | 21–25 | 52·31 | 50·55 | 51·96 | 49·59 | 49·22 | 51·94 | 49·42 |
| | 26–31 | 51·86 | 49·60 | 51·48 | 48·73 | 49·19 | 51·45 | 48·69 |
| November | 1–5 | 51·19 | 48·89 | 50·80 | 48·43 | 48·89 | 50·77 | 48·39 |
| | 6–10 | 50·66 | 48·69 | 50·20 | 48·12 | 48·69 | 50·18 | 48·10 |
| | 11–15 | 50·14 | 48·47 | 49·75 | 47·90 | 48·47 | 49·72 | 47·87 |
| | 16–20 | 49·81 | 48·23 | 49·35 | 47·80 | 48·23 | 49·33 | 47·67 |
| | 21–25 | 49·50 | 48·08 | 49·13 | 48·11 | 48·08 | 49·09 | 47·47 |
| | 26–30 | 49·24 | 47·90 | 48·90 | 48·10 | 47·90 | 48·87 | 47·43 |
| December | 1– 5 | 48·97 | 47·53 | 48·60 | 48·06 | 47·53 | 48·58 | 47·41 |
| | 6–10 | 48·77 | 47·26 | 48·29 | 48·00 | 47·24 | 48·27 | 47·41 |
| | 11–15 | 48·58 | 47·48 | 48·13 | 48·00 | 47·26 | 48·12 | 47·40 |
| | 16–20 | 48·42 | 47·76 | 48·64 | 47·98 | 47·22 | 47·97 | 47·34 |
| | 21–25 | 48·29 | 47·68 | 48·76 | 48·08 | 47·28 | 47·88 | 47·24 |
| | 26–31 | 48·16 | 47·59 | 48·89 | 47·92 | 47·37 | 47·77 | 47·26 |

The Assiut Barrage began operating in 1903.

TABLE 86.—RODA (CAIRO) GAUGE.
(Five-day means. R.L. in metres above mean sea).

| Date. | | 1892. | 1907. | 1908. | 1912. | Mean, 1873–1910. |
|---|---|---|---|---|---|---|
| January | 1– 5 | 15·02 | 15·12 | 15·09 | 14·86 | 15·10 |
| | 6–10 | 14·89 | 15·03 | 14·92 | 14·82 | 15·00 |
| | 11–15 | 14·74 | 14·97 | 14·85 | 14·77 | 14·91 |
| | 16–20 | 14·57 | 14·94 | 14·79 | 14·67 | 14·81 |
| | 21–25 | 14·49 | 15·02 | 14·90 | 14·59 | 14·73 |
| | 26–31 | 14·39 | 15·30 | 15·19 | 14·61 | 14·66 |
| February | 1– 5 | 14·28 | 15·28 | 15·13 | 15·10 | 14·63 |
| | 6–10 | 14·31 | 15·25 | 15·05 | 15·19 | 14·60 |
| | 11–15 | 14·27 | 15·32 | 15·01 | 15·16 | 14·57 |
| | 16–20 | 14·22 | 15·28 | 14·97 | 15·11 | 14·53 |
| | 21–25 | 14·19 | 15·25 | 14·95 | 15·14 | 14·49 |
| | 26–end | 14·12 | 15·25 | 15·02 | 15·16 | 14·45 |
| March | 1– 5 | 14·06 | 15·22 | 14·98 | 15·16 | 14·42 |
| | 6–10 | 14·00 | 15·14 | 14·93 | 15·16 | 14·37 |
| | 11–15 | 13·95 | 15·12 | 14·95 | 15·30 | 14·32 |
| | 16–20 | 13·92 | 15·10 | 14·88 | 15·17 | 14·29 |
| | 21–25 | 13·89 | 15·06 | 14·76 | 15·00 | 14·22 |
| | 26–31 | 13·99 | 15·01 | 14·97 | 14·98 | 14·18 |
| April | 1– 5 | 14·05 | 14·85 | 15·05 | 14·92 | 14·12 |
| | 6–10 | 14·03 | 14·73 | 14·82 | 14·92 | 14·07 |
| | 11–15 | 14·01 | 14·80 | 14·60 | 15·00 | 14·02 |
| | 16–20 | 14·00 | 14·91 | 14·51 | 15·01 | 13·99 |
| | 21–25 | 13·99 | 14·88 | 14·49 | 15·01 | 13·95 |
| | 26–30 | 13·98 | 14·90 | 14·58 | 14·99 | 13·92 |
| May | 1– 5 | 13·98 | 14·90 | 14·67 | 15·02 | 13·88 |
| | 6–10 | 13·96 | 14·94 | 14·68 | 14·99 | 13·85 |
| | 11–15 | 13·91 | 14·91 | 14·74 | 15·00 | 13·82 |
| | 16–20 | 13·91 | 14·83 | 14·79 | 14·92 | 13·78 |
| | 21–25 | 13·80 | 14·82 | 14·76 | 14·94 | 13·76 |
| | 26–31 | 13·72 | 14·84 | 14·75 | 14·89 | 13·73 |
| June | 1– 5 | 13·69 | 14·80 | 14·73 | 14·85 | 13·71 |
| | 6–10 | 13·62 | 14·72 | 14·75 | 14·92 | 13·71 |
| | 11–15 | 13·56 | 14·71 | 14·77 | 14·94 | 13·72 |
| | 16–20 | 13·51 | 14·69 | 14·73 | 14·90 | 13·75 |
| | 21–25 | 13·52 | 14·70 | 14·73 | 14·89 | 13·79 |
| | 26–30 | 13·56 | 14·66 | 14·81 | 14·95 | 13·85 |

TABLE 86 (*continued*).

| Date. | | 1892. | 1907. | 1908. | 1912. | Mean, 1873–1910. |
|---|---|---|---|---|---|---|
| July | 1– 5 | 13·61 | 14·77 | 14·81 | 14·96 | 13·93 |
| | 6–10 | 13·71 | 14·85 | 14·81 | 14·94 | 14·05 |
| | 11–15 | 13·87 | 14·97 | 14·84 | 14·95 | 14·21 |
| | 16–20 | 14·12 | 15·19 | 14·89 | 15·08 | 14·42 |
| | 21–25 | 14·40 | 15·62 | 15·09 | 15·28 | 14·68 |
| | 26–31 | 14·62 | 15·86 | 15·70 | 15·68 | 15·16 |
| August | 1– 5 | 15·53 | 15·98 | 15·90 | 15·88 | 15·85 |
| | 6–10 | 17·17 | 16·23 | 16·23 | 16·15 | 16·59 |
| | 11–15 | 17·85 | 16·52 | 16·64 | 17·32 | 17·35 |
| | 16–20 | 17·84 | 16·62 | 17·57 | 18·07 | 17·85 |
| | 21–25 | 17·86 | 16·78 | 18·52 | 18·42 | 18·10 |
| | 26–31 | 18·60 | 17·16 | 18·94 | 18·38 | 18·39 |
| September | 1– 5 | 19·03 | 17·61 | 19·01 | 18·33 | 18·58 |
| | 6–10 | 19·23 | 18·01 | 19·10 | 18·32 | 18·72 |
| | 11–15 | 19·58 | 17·95 | 19·26 | 18·43 | 18·83 |
| | 16–20 | 19·99 | 17·93 | 19·60 | 18·17 | 18·93 |
| | 21–25 | 20·31 | 17·94 | 19·94 | 17·93 | 19·02 |
| | 26–30 | 20·50 | 17·99 | 20·12 | 17·86 | 19·07 |
| October | 1– 5 | 20·62 | 17·88 | 19·93 | 17·88 | 19·02 |
| | 6–10 | 20·58 | 17·77 | 19·52 | 17·80 | 18·96 |
| | 11–15 | 20·41 | 17·63 | 19·61 | 17·68 | 18·95 |
| | 16–20 | 20·22 | 17·41 | 19·72 | 17·50 | 18·93 |
| | 21–25 | 20·09 | 17·28 | 19·78 | 17·57 | 18·86 |
| | 26–31 | 20·13 | 17·16 | 19·58 | 17·21 | 18·60 |
| November | 1– 5 | 19·71 | 17·13 | 18·93 | 16·94 | 18·09 |
| | 6–10 | 18·98 | 17·11 | 18·31 | 16·82 | 17·61 |
| | 11–15 | 18·13 | 17·11 | 17·71 | 16·63 | 17·16 |
| | 16–20 | 17·34 | 16·91 | 17·34 | 16·55 | 16·78 |
| | 21–25 | 16·79 | 16·77 | 17·03 | 16·36 | 16·48 |
| | 26–30 | 16·48 | 16·67 | 16·92 | 16·05 | 16·24 |
| December | 1– 5 | 16·23 | 16·48 | 16·74 | 16·03 | 16·05 |
| | 6–10 | 15·99 | 16·31 | 16·48 | 16·05 | 15·87 |
| | 11–15 | 15·85 | 16·06 | 16·13 | 16·08 | 15·72 |
| | 16–20 | 15·64 | 15·99 | 15·65 | 15·59 | 15·56 |
| | 21–25 | 15·53 | 15·52 | 15·38 | 15·18 | 15·39 |
| | 26–31 | 15·42 | 15·13 | 15·20 | 15·11 | 15·23 |

TABLE 87.—DELTA BARRAGE GAUGE.
(Five-day means. R.L. in metres above mean sea.)

| Date. | | Rosetta Branch Barrage (upstream). | | | |
|---|---|---|---|---|---|
| | | 1892. | 1907. | 1908. | 1912. |
| January | 1– 5 | 13·54 | 15·12 | 15·09 | 13·74 |
| | 6–10 | 13·43 | 15·03 | 14·92 | 13·72 |
| | 11–15 | 13·31 | 14·97 | 14·84 | 13·70 |
| | 16–20 | 13·19 | 14·94 | 14·79 | 13·64 |
| | 21–25 | 13·11 | 15·02 | 14·90 | 13·56 |
| | 26–31 | 13·03 | 15·29 | 15·12 | 13·85 |
| February | 1– 5 | 13·00 | 15·28 | 15·15 | 14·59 |
| | 6–10 | 13·21 | 15·25 | 15·05 | 14·71 |
| | 11–15 | 13·30 | 15·32 | 15·01 | 14·75 |
| | 16–20 | 13·32 | 15·28 | 14·97 | 14·71 |
| | 21–25 | 13·38 | 15·25 | 14·96 | 14·79 |
| | 26–end | 13·38 | 15·25 | 15·02 | 14·81 |
| March | 1– 5 | 13·40 | 15·19 | 14·98 | 14·81 |
| | 6–10 | 13·41 | 15·14 | 14·93 | 14·82 |
| | 11–15 | 13·42 | 15·12 | 14·93 | 14·97 |
| | 16–20 | 13·44 | 15·11 | 14·90 | 14·88 |
| | 21–25 | 13·44 | 15·06 | 14·75 | 14·72 |
| | 26–31 | 13·58 | 15·01 | 14·87 | 14·71 |
| April | 1– 5 | 13·68 | 14·85 | 14·97 | 14·65 |
| | 6–10 | 13·68 | 14·73 | 14·78 | 14·65 |
| | 11–15 | 13·68 | 14·78 | 14·49 | 14·71 |
| | 16–20 | 13·68 | 14·90 | 14·40 | 14·83 |
| | 21–25 | 13·67 | 14·88 | 14·40 | 14·79 |
| | 26–30 | 13·68 | 14·90 | 14·46 | 14·73 |
| May | 1– 5 | 13·68 | 14·90 | 14·52 | 14·75 |
| | 6–10 | 13·67 | 14·93 | 14·46 | 14·72 |
| | 11–15 | 13·63 | 14·90 | 14·53 | 14·73 |
| | 16–20 | 13·62 | 14·83 | 14·70 | 14·66 |
| | 21–25 | 13·52 | 14·82 | 14·76 | 14·67 |
| | 26–31 | 13·46 | 14·84 | 14·75 | 14·63 |
| June | 1– 5 | 13·40 | 14·81 | 14·74 | 14·59 |
| | 6–10 | 13·35 | 14·72 | 14·75 | 14·67 |
| | 11–15 | 13·30 | 14·71 | 14·77 | 14·67 |
| | 16–20 | 13·24 | 14·69 | 14·73 | 14·63 |
| | 21–25 | 13·24 | 14·70 | 14·73 | 14·62 |
| | 26–30 | 13·28 | 14·66 | 14·81 | 14·67 |

TABLE 87 (*continued*).

| Date. | | Rosetta Branch Barrage (upstream). | | | |
|---|---|---|---|---|---|
| | | 1892. | 1907. | 1908. | 1912. |
| July | 1– 5 | 13·33 | 14·77 | 14·81 | 14·67 |
| | 6–10 | 13·43 | 14·85 | 14·81 | 14·66 |
| | 11–15 | 13·56 | 14·97 | 14·85 | 14·67 |
| | 16–20 | 13·78 | 15·19 | 14·89 | 14·79 |
| | 21–25 | 14·02 | 15·62 | 15·09 | 14·99 |
| | 26–31 | 14·03 | 15·86 | 15·83 | 15·35 |
| August | 1– 5 | 14·06 | 15·97 | 15·90 | 15·53 |
| | 6–10 | 15·12 | 16·23 | 16·23 | 15·68 |
| | 11–15 | 15·69 | 16·52 | 16·64 | 15·96 |
| | 16–20 | 15·71 | 16·62 | 17·55 | 16·25 |
| | 21–25 | 15·72 | 16·77 | 18·52 | 16·37 |
| | 26–31 | 16·24 | 17·16 | 18·93 | 16·28 |
| September | 1– 5 | 16·71 | 17·60 | 16·66 | 16·21 |
| | 6–10 | 16·89 | 18·00 | 16·70 | 16·19 |
| | 11–15 | 17·20 | 17·95 | 16·84 | 16·29 |
| | 16–20 | 17·58 | 17·93 | 17·16 | 15·91 |
| | 21–25 | 17·86 | 17·94 | 17·45 | 15·66 |
| | 26–30 | 18·07 | 17·99 | 17·62 | 15·72 |
| October | 1– 5 | 18·22 | 17·88 | 17·50 | 15·97 |
| | 6–10 | 18·22 | 17·77 | 17·11 | 16·01 |
| | 11–15 | 18·07 | 17·65 | 17·17 | 16·05 |
| | 16–20 | 17·92 | 17·41 | 17·27 | 16·06 |
| | 21–25 | 17·79 | 17·28 | 17·35 | 16·07 |
| | 26–31 | 17·83 | 17·17 | 17·20 | 15·98 |
| November | 1– 5 | 17·49 | 17·12 | 16·65 | 15·90 |
| | 6–10 | 16·86 | 17·11 | 16·21 | 15·86 |
| | 11–15 | 16·16 | 17·11 | 15·72 | 15·81 |
| | 16–20 | 15·56 | 16·91 | 15·74 | 15·80 |
| | 21–25 | 15·08 | 16·77 | 15·68 | 15·75 |
| | 26–30 | 14·77 | 16·66 | 15·79 | 15·48 |
| December | 1– 5 | 14·48 | 16·48 | 15·67 | 15·43 |
| | 6–10 | 14·32 | 16·30 | 15·51 | 15·49 |
| | 11–15 | 14·26 | 16·06 | 15·16 | 15·50 |
| | 16–20 | 14·04 | 15·99 | 14·47 | 14·86 |
| | 21–25 | 14·01 | 15·52 | 13·93 | 14·30 |
| | 26–31 | 13·91 | 15·13 | 13·81 | 14·27 |

TABLE 88.—TAMANIAT GAUGES.
(Ten-day means in metres.)

| Date, 1912. | | Ten-day Mean Gauge Reading. |
|---|---|---|
| May | 21–31 | 9·65 |
| June | 1–10 | 9·67 |
| | 11–20 | 9·99 |
| | 21–30 | 10·80 |
| July | 1–10 | 11·30 |
| | 11–20 | 11·84 |
| | 21–31 | 13·51 |
| August | 1–10 | 14·70 |
| | 11–20 | 15·39 |
| | 21–31 | 15·51 |
| September | 1–10 | 15·30 |
| | 11–20 | 14·94 |
| | 21–30 | 14·63 |
| October | 1–10 | 13·60 |
| | 11–20 | 12·99 |
| | 21–31 | 12·57 |
| November | 1–10 | 12·31 |
| | 11–20 | 12·10 |
| | 21–30 | 11·82 |
| December | 1–10 | 11·61 |
| | 11–20 | 11·40 |
| | 21–31 | 11·20 |

R.L. of zero, 360·13 metres.

We now give some interesting gauges for certain maximum and minimum years:—

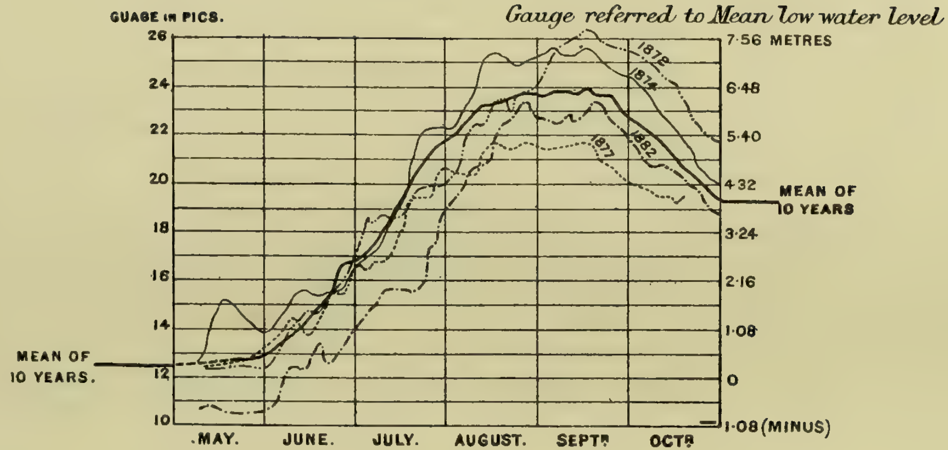
*Khartoum* gauge, 1878, the highest flood of which there is any record. It is remembered as the "Bayuda" or "Mosquito" year.

*Aswan.*—We give guiding gauges for 1874, 1878, 1892 (years of high flood), for 1877 (the year of lowest flood), and 1879 (the highest summer supply of which there is any record).

*Cairo* (*Roda*).—Guiding gauges for 1874, 1878, and 1892. In October 1878 the left bank of the Nile upstream of the gauge was very badly breached.

TABLE 89.—KHARTOUM GAUGE, 1878.
(R.L. in metres above mean sea.)

| Days. | May. | June. | July. | August. | September. | October. |
|---|---|---|---|---|---|---|
| 1 | ... | 374·89 | 377·45 | 379·11 | 381·27 | 382·01 |
| 2 | ... | 374·99 | 377·35 | 379·22 | 381·40 | 381·92 |
| 3 | ... | 374·42 | 377·31 | 379·51 | 381·45 | 381·99 |
| 4 | ... | 374·60 | 377·26 | 379·92 | 381·56 | 381·81 |
| 5 | ... | 374·94 | 377·26 | 380·12 | 381·63 | 381·63 |
| 6 | ... | 376·23 | 377·49 | 380·19 | 381·70 | 381·54 |
| 7 | ... | 376·30 | 377·58 | 380·32 | 381·79 | 381·49 |
| 8 | ... | 376·37 | 377·76 | 380·32 | 381·77 | 381·45 |
| 9 | ... | 376·48 | 377·78 | 380·32 | 381·85 | 381·40 |
| 10 | 374·86 | 376·43 | 377·78 | 380·32 | 381·90 | 381·36 |
| 11 | 374·86 | 376·43 | 377·85 | 380·66 | 381·97 | 381·27 |
| 12 | 374·86 | 376·43 | 378·17 | 380·75 | 382·06 | 381·16 |
| 13 | 374·86 | 376·45 | 378·25 | 380·86 | 382·06 | 381·11 |
| 14 | 374·86 | 376·54 | 378·32 | 380·86 | 382·12 | 381·07 |
| 15 | 374·86 | 376·61 | 378·32 | 380·93 | 382·12 | 381·00 |
| 16 | 374·86 | 376·61 | 378·32 | 381·02 | 382·17 | 380·93 |
| 17 | 374·86 | 376·59 | 378·32 | 381·02 | 382·21 | 380·89 |
| 18 | 374·86 | 376·54 | 378·32 | 380·95 | 382·28 | 380·84 |
| 19 | 374·86 | 376·50 | 378·37 | 380·89 | 382·28 | 380·77 |
| 20 | 374·86 | 376·52 | 378·84 | 380·82 | 382·37 | 380·73 |
| 21 | 374·86 | 376·61 | 378·88 | 380·82 | 382·39 | 380·59 |
| 22 | 374·79 | 376·57 | 378·86 | 380·59 | 382·39 | 380·53 |
| 23 | 374·81 | 376·63 | 378·91 | 380·48 | 382·33 | 380·46 |
| 24 | 374·81 | 376·86 | 379·11 | 380·57 | 382·24 | 380·37 |
| 25 | 374·95 | 377·02 | 379·02 | 380·73 | 382·24 | 380·28 |
| 26 | 374·92 | 377·06 | 379·02 | 380·73 | 382·24 | 380·19 |
| 27 | 374·86 | 377·08 | 379·02 | 380·75 | 382·19 | 380·10 |
| 28 | 374·79 | 377·22 | 379·02 | 380·95 | 382·19 | 380·05 |
| 29 | 374·86 | 377·31 | 379·04 | 380·95 | 382·19 | 380·01 |
| 30 | 374·83 | 377·42 | 379·11 | 381·13 | 382·08 | |
| 31 | 374·83 | ... | 379·11 | 381·25 | | |

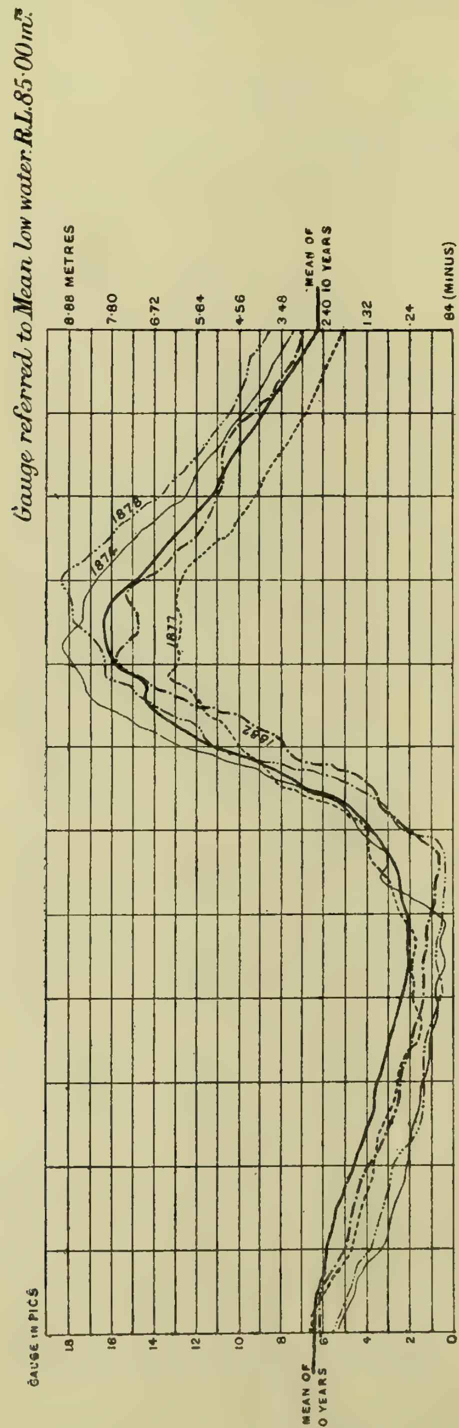



*The Khartoum gauge stood on the Blue Nile about 5 kilometres above the Junction at Khartoum. Distance from sea about 3000 kilometres The 1878 gauge was much higher than the 1874 gauge, at Khartoum, than at Assuan. The Atbára must have made the difference. The 1874 flood was an early; torrential flood, it fell early, and was followed by a fairly low summer. The 1878 flood was a late one, (from the great basin regions) it fell late, and was followed by the highest summer on record.*

FIG. 15.—Khartoum Gauge Diagram, 1874, 1877, 1878, 1882, and average of ten years, 1874 to 1883.

TABLE 90.—ASWAN GAUGE.
(R.L. in metres above mean sea.)

| Date. | | 1874. | 1877. | 1878. | 1879. | 1892. |
|---|---|---|---|---|---|---|
| January | 1 | 87·06 | 87·62 | 86·97 | 88·70 | 87·78 |
| February | 1 | 85·94 | 86·77 | 86·21 | 88·12 | 86·99 |
| March | 1 | 85·28 | 86·14 | 85·44 | 87·74 | 86·00 |
| April | 1 | 84·88 | 85·46 | 84·90 | 87·44 | 85·26 |
| May | 1 | 84·59 | 85·35 | 84·59 | | 84·70 |
| | 23 | ... | ... | ... | 87·24 | |
| | 27 | ... | **85·10** | ... | **86·88** | |
| | 29 | **84·34** | | | | |
| June | 1 | 84·68 | 85·19 | 84·34 | 87·20 | **84·40** |
| | 9 | ... | ... | **84·29** | | |
| | 20 | 85·64 | 86·09 | 84·41 | 87·29 | 84·63 |
| July | 1 | 86·50 | 86·30 | 85·67 | 87·35 | 85·28 |
| | 10 | 87·15 | 87·13 | 86·05 | 88·48 | 85·98 |
| | 20 | 88·37 | 88·23 | 87·47 | 89·58 | 87·35 |
| August | 1 | 91·49 | 89·72 | 90·39 | 90·66 | 90·75 |
| | 10 | 92·35 | 90·35 | 91·25 | 92·06 | 91·76 |
| | 20 | 93·56 | 91·40 | 92·48 | 93·19 | 92·35 |
| September | 1 | 93·70 | 91·18 | 92·60 | 92·96 | 93·30 |
| | 5 | ... | **91·27** | | | |
| | 6 | **93·97** | | | | |
| | 10 | 93·83 | 91·09 | 93·52 | 93·18 | 93·81 |
| | 13 | ... | ... | ... | **93·70** | |
| | 20 | 93·43 | 90·95 | 93·86 | 93·27 | **93·88** |
| October | 1 | 93·11 | 91·04 | **94·15** | 92·64 | 93·36 |
| | 10 | 92·64 | 90·21 | 93·47 | 91·97 | 92·78 |
| | 20 | 91·61 | 89·63 | 92·60 | 91·36 | 92·15 |
| November | 1 | 90·48 | 88·88 | 91·72 | 90·48 | 91·16 |
| | 10 | 89·87 | 88·61 | 90·86 | 89·87 | 90·28 |
| | 20 | 89·31 | 88·23 | 90·17 | 89·42 | 89·63 |
| December | 1 | 88·95 | 87·60 | 89·67 | 89·06 | 89·06 |
| | 15 | 88·41 | 87·22 | 89·20 | 88·70 | 88·59 |
| | 31 | 88·01 | 86·99 | 88·75 | 88·41 | 88·28 |




*Assuan Gauge zero 84·16 metres above mean sea_1204 kilometres from sea (Rosetta Branch)*

*1874, 1878, Highest floods on record, Inundations* ‖ *1874 Maximum early in September, not so bad for*
*1877, Lowest flood_Famine in Upper Egypt.* ‖ *the country as 1878 with maximum in October.*

*The mean of the 10 years just above 16 pics for 20 days_favourable in every way.*

FIG. 16.—Aswan Gauge Diagram, 1874, 1877, 1878, 1882, and average of ten years, 1874 to 1883.

TABLE 91.—CAIRO (RODA) GAUGE.
(R.L. in metres above sea-level.)

| Date. | | 1874. | 1877. | 1878. | 1879. | 1892. |
|---|---|---|---|---|---|---|
| January | 1 . . | 15·05 | 14·97 | 14·52 | 16·20 | 15·11 |
| February | 1 . . | 14·16 | 14·43 | 13·89 | 15·38 | 14·30 |
| March | 1 . . | 13·69 | 13·78 | 13·28 | 15·01 | 14·09 |
| April | 1 . . | 13·28 | 13·53 | 12·97 | 14·75 | 14·05 |
| May | 1 . . | 12·95 | 13·15 | 12·54 | 14·63 | 14·00 |
| June | 1 . . | 12·66 | 12·97 | 12·27 | 14·25 | 13·69 |
| | 4 . . | ... | ... | ... | **14·21** | |
| | 13 . . | **12·61** | | | | |
| | 14 . . | ... | **12·83** | ... | ... | **13·49** |
| | 21 . . | | | | | |
| | 28 . . | ... | ... | **12·00** | | |
| July | 1 . . | 13·19 | 13·42 | 12·05 | 14·32 | 13·58 |
| | 10 . . | 13·78 | 13 44 | 12·59 | 14·39 | 13·80 |
| | 20 . . | 14·48 | 13·82 | 13·22 | 15·73 | 14·30 |
| August | 1 . . | 17·17 | 15·07 | 15·24 | 17·19 | 15·07 |
| | 10 . . | 18·72 | 16·24 | 17·10 | 18·16 | 17·56 |
| | 20 . . | 19·51 | 16·85 | 18·22 | 19·12 | 17·65 |
| | 27 . . | ... | **17·65** | | | |
| September | 1 . . | 19·84 | 17·50 | 18·85 | 19·30 | 18·93 |
| | 10 . . | 20·36 | 17·52 | 19·08 | 19·28 | 19·37 |
| | 20 . . | 20·88 | 17·43 | 19·82 | 19·91 | 20·26 |
| October | 1 . . | 21·01 | 17·49 | 20·68 | **20·29** | 20·59 |
| | 6 . . | **21·40** | | | | |
| | 7 . . | ... | ... | ... | ... | **20·63** |
| | 10 . . | 21·24 | 17·28 | 21·24 | 19·73 | 20·52 |
| | 11 . . | ... | ... | **21·26** | | |
| | 20 . . | 20·36 | 16·81 | 20·81 | 19·66 | 20·14 |
| November | 1 . . | 19·15 | 16·38 | 20·02 | 18·70 | 19·96 |
| | 10 . . | 17·87 | 15·84 | 19·66 | 17·60 | 18·61 |
| | 20 . . | 16·90 | 15·91 | 18·39 | 16·99 | 17·08 |
| December | 1 . . | 16·51 | 15·34 | 17·32 | 16·54 | 16·38 |
| | 10 . . | 16·27 | 14·95 | 16·94 | 16·20 | 15·91 |
| | 20 . . | 15·88 | 14·72 | 16·60 | 15·93 | 15·58 |
| | 31 . . | 15·32 | 14·54 | 16·24 | 15·70 | 15·34 |

In 1879 the Delta Barrages were not regulated on in summer.

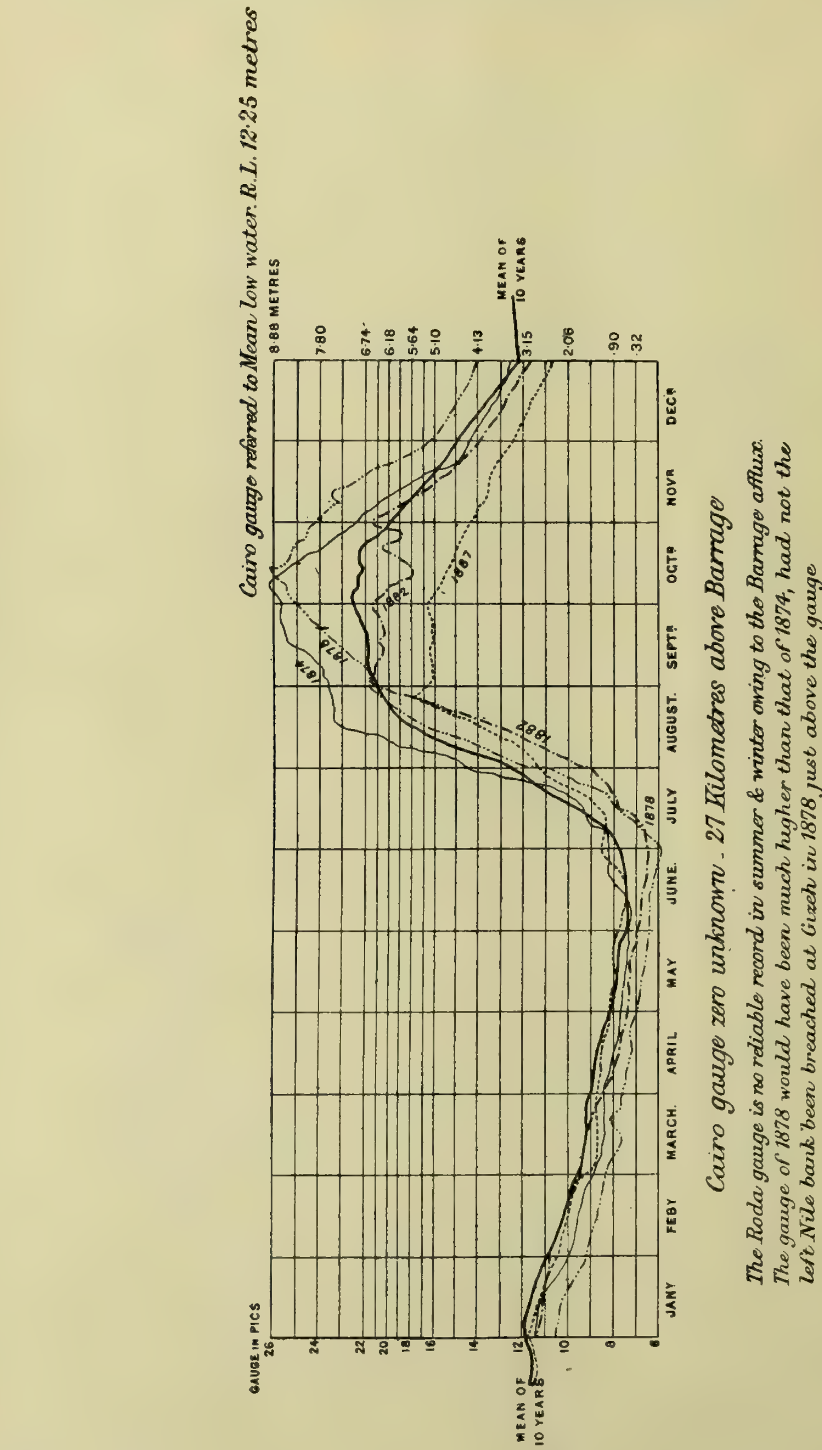



FIG. 17.—Cairo Gauge Diagram, 1874, 1877, 1878, and average of ten years, 1874 to 1883.

The paragraph is brought to a close by the following tables :—

Two tables giving the maximum and minimum gauges at Khartoum and Aswan.

Two tables for converting pics and kirats on the Aswan and Roda gauges to reduced levels in metres above mean sea.

Table of ten-day mean gauges for 1912 on the Upper Nile.

Table of Upper Nile gauges, 1912, not read regularly.

TABLE 92.—DETAILS OF EARLIEST AND LATEST DATES OF MAXIMUM AND MINIMUM LEVELS AT KHARTOUM.

| Year. | Date of Lowest Reading. | Difference from Mean Date. | Date of Highest Reading. | Difference from Mean Date. |
|---|---|---|---|---|
| 1869 | May 19 | + 9 | Sept. 5 | + 4 |
| 1870 | May 20 | + 10 | Aug. 17 | − 15 |
| 1871 | 17 | + 7 | 16 | − 16 |
| 1872 | 8 | − 2 | Sept. 6 | + 5 |
| 1873 | 12 | + 2 | 2–10 | + 1 |
| 1874 | 8 | − 2 | 4–5 | + 3 |
| 1875 | 8 | − 2 | 20 | + 19 |
| 1876 | 8 | − 2 | 12 | + 11 |
| 1877 | 10 | ... | Aug. 29–30 | − 3 |
| 1878 | 10 | ... | Sept. 21–22 | + 20 |
| 1879 | 10 | ... | 9–11 | + 8 |
| 1880 | April 13 | + 3 | Sept. 23 | + 22 |
| 1881 | 20 | + 10 | 29 | + 28 |
| 1882 | 29 | + 19 | Aug. 28 | − 4 |
| 1883 | 24 | + 14 | Sept. 11 | + 10 |
| 1900 | April 16 | − 24 | Aug. 17 | − 15 |
| 1901 | 18 | − 22 | 1–20 | − 31 |
| 1902 | May 6 | − 4 | 14 | − 18 |
| 1903 | 15 | + 5 | 4 | − 28 |
| 1904 | 10 | ... | 11 | − 21 |
| 1905 | 5 | − 5 | Sept. 6 | + 5 |
| 1906 | 28 | + 18 | 14 | + 13 |
| 1907 | 28 | + 18 | Aug. 27 | − 5 |
| 1908 | 9 | − 1 | Sept. 3 | + 2 |
| 1909 | Apr. 8 | − 33 | Aug. 30 | − 2 |
| 1910 | May 13 | + 3 | Sept. 9 | + 8 |
| 1911 | 5 | − 5 | 8 | + 7 |
| 1912 | 14 | + 4 | Aug. 31 | + 1 |

Mean date of lowest reading, 10th May.
,, highest reading, 1st September.

TABLE 93.—DATE OF HEIGHTS OF MINIMUM GAUGES IN SUMMER AND MAXIMUM GAUGES IN FLOOD AT ASWAN (R.L. in metres).

| Year. | Minimum Summer. | | Maximum Flood. | |
|---|---|---|---|---|
| | Date. | Gauges. | Date. | Gauges. |
| 1873 | June 5 . . | 84·63 | September 7 . . | 92·71 |
| 1874 | May 30 . . | 84·34 | 6 . . | 93·97 |
| 1875 | 23 . . | 84·83 | 11 . . | 93·36 |
| 1876 | June 15 . . | 85·13 | 7 . . | 93·66 |
| 1877 | May 27 . . | 85·10 | August 20 . . | 91·40 |
| 1878 | June 9 . . | 84·29 | October 1 . . | 94·15 |
| 1879 | May 23 . . | 86·88 | September 13 . . | 93·70 |
| 1880 | June 3 . . | 85·82 | September 4 . . | 92·82 |
| 1881 | May 14 . . | 84·99 | 21 . . | 93·11 |
| 1882 | June 21 . . | 84·45 | August 28 . . | 93·00 |
| 1883 | 21 . . | 85·04 | September 17 . . | 93·13 |
| 1884 | May 27 . . | 85·37 | 1 . . | 92·73 |
| 1885 | June 21 . . | 84·56 | August 28 . . | 93·00 |
| 1886 | 3 . . | 84·94 | September 22 . . | 93·04 |
| 1887 | May 5 . . | 84·97 | 1 . . | 93·81 |
| 1888 | June 8 . . | 84·94 | August 24 . . | 92·08 |
| 1889 | 4 . . | 84·40 | September 2 . . | 93·36 |
| 1890 | May 28 . . | 84·40 | September 2 . . | 93·72 |
| 1891 | 19 . . | 84·79 | 16 . . | 92·93 |
| 1892 | June 4 . . | 84·36 | 20 . . | 93·88 |
| 1893 | 18 . . | 85·35 | 14 . . | 92·75 |
| 1894 | May 9 . . | 84·97 | August 26 . . | 93·70 |
| 1895 | June 23 . . | 85·71 | 22 . . | 93·74 |
| 1896 | 13 . . | 85·48 | September 3 . . | 93·63 |
| 1897 | May 31 . . | 85·62 | 1 . . | 92·80 |
| 1898 | June 23 . . | 84·74 | August 29 . . | 93·63 |
| 1899 | 1 . . | 85·15 | September 4 . . | 91·67 |
| 1900 | May 15 . . | 84·07 | August 19 . . | 92·91 |
| 1901 | 10 . . | 84·54 | September 6 . . | 92·82 |
| 1902 | June 6 . . | 84·42 | 17 . . | 91·72 |
| 1903 | April 16 . . | 84·32 | August 27 . . | 92·93 |
| 1904 | May 4 . . | 84·79 | 13 . . | 91·97 |
| 1905 | 1 . . | 84·41 | September 18 . | 91·86 |
| 1906 | 10 . . | 84·50 | 20 . | 92·78 |
| 1907 | March 25 . . | 84·84 | 3 . . | 91·52 |
| 1908 | May 10–June 15 . | 84·50 | 10 . . | 93·30 |
| 1909 | April 8–17 . . | 85·00 | 11 . . | 93·16 |
| 1910 | May 3 . . | 84·89 | September 4 . . | 93·05 |
| 1911 | 6 . . | 85·00 | 16 . . | 92·68 |
| 1912 | April 15–June 1 . | 84·80 | August 20 . . | 92·05 |

Mean date for maximum flood, 6th September.

| Kirats. \ Pics. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 84.16 | 84.70 | 85.24 | 85.78 | 86.32 | 86.86 | 87.40 | 87.94 | 88.48 | 89.02 | 89.56 | 90.10 | 90.64 | 91.18 | 91.72 | 92.26 | 92.80 | 93.34 | 93.88 |
| | 84.17 | 84.71 | 85.25 | 85.79 | 86.33 | 86.87 | 87.41 | 87.95 | 88.49 | 89.03 | 89.57 | 90.11 | 90.65 | 91.19 | 91.73 | 92.27 | 92.81 | 93.35 | 93.89 |
| 1 | 84.18 | 84.72 | 85.26 | 85.80 | 86.34 | 86.88 | 87.42 | 87.96 | 88.50 | 89.04 | 89.58 | 90.12 | 90.66 | 91.20 | 91.74 | 92.28 | 92.82 | 93.36 | 93.90 |
| | 84.19 | 84.73 | 85.27 | 85.81 | 86.35 | 86.89 | 87.43 | 87.97 | 88.51 | 89.05 | 89.59 | 90.13 | 90.67 | 91.21 | 91.75 | 92.29 | 92.83 | 93.37 | 93.91 |
| 2 | 84.20 | 84.74 | 85.28 | 85.82 | 86.36 | 86.90 | 87.44 | 87.98 | 88.52 | 89.06 | 89.60 | 90.14 | 90.68 | 91.22 | 91.76 | 92.30 | 92.84 | 93.38 | 93.92 |
| | 84.21 | 84.75 | 85.29 | 85.83 | 86.37 | 86.91 | 87.45 | 87.99 | 88.53 | 89.07 | 89.61 | 90.15 | 90.69 | 91.23 | 91.77 | 92.31 | 92.85 | 93.39 | 93.93 |
| 3 | 84.22 | 84.76 | 85.30 | 85.84 | 86.38 | 86.92 | 87.46 | 88.00 | 88.54 | 89.08 | 89.62 | 90.16 | 90.70 | 91.24 | 91.78 | 92.32 | 92.86 | 93.40 | 93.94 |
| | 84.23 | 84.77 | 85.31 | 85.85 | 86.39 | 86.93 | 87.47 | 88.01 | 88.55 | 89.09 | 89.63 | 90.17 | 90.71 | 91.25 | 91.79 | 92.33 | 92.87 | 93.41 | 93.95 |
| 4 | 84.24 | 84.78 | 85.32 | 85.86 | 86.40 | 86.94 | 87.48 | 88.02 | 88.56 | 89.10 | 89.64 | 90.18 | 90.72 | 91.26 | 91.80 | 92.34 | 92.88 | 93.42 | 93.96 |
| | 84.25 | 84.79 | 85.33 | 85.87 | 86.41 | 86.95 | 87.49 | 88.03 | 88.57 | 89.11 | 89.65 | 90.19 | 90.73 | 91.27 | 91.81 | 92.35 | 92.89 | 93.43 | 93.97 |
| | 84.26 | 84.80 | 85.34 | 85.88 | 86.42 | 86.96 | 87.50 | 88.04 | 88.58 | 89.12 | 89.66 | 90.20 | 90.74 | 91.28 | 91.82 | 92.36 | 92.90 | 93.44 | 93.98 |
| 5 | 84.27 | 84.81 | 85.35 | 85.89 | 86.43 | 86.97 | 87.51 | 88.05 | 88.59 | 89.13 | 89.67 | 90.21 | 90.75 | 91.29 | 91.83 | 92.37 | 92.91 | 93.45 | 93.99 |
| | 84.28 | 84.82 | 85.36 | 85.90 | 86.44 | 86.98 | 87.52 | 88.06 | 88.60 | 89.14 | 89.68 | 90.22 | 90.76 | 91.30 | 91.84 | 92.38 | 92.92 | 93.46 | 94.00 |
| 6 | 84.29 | 84.83 | 85.37 | 85.91 | 86.45 | 86.99 | 87.53 | 88.07 | 88.61 | 89.15 | 89.69 | 90.23 | 90.77 | 91.31 | 91.85 | 92.39 | 92.93 | 93.47 | 94.01 |
| | 84.30 | 84.84 | 85.38 | 85.92 | 86.46 | 87.00 | 87.54 | 88.08 | 88.62 | 89.16 | 89.70 | 90.24 | 90.78 | 91.32 | 91.86 | 92.40 | 92.94 | 93.48 | 94.02 |
| 7 | 84.31 | 84.85 | 85.39 | 85.93 | 86.47 | 87.01 | 87.55 | 88.09 | 88.63 | 89.17 | 89.71 | 90.25 | 90.79 | 91.33 | 91.87 | 92.41 | 92.95 | 93.49 | 94.03 |
| | 84.32 | 84.86 | 85.40 | 85.94 | 86.48 | 87.02 | 87.56 | 88.10 | 88.64 | 89.18 | 89.72 | 90.26 | 90.80 | 91.34 | 91.88 | 92.42 | 92.96 | 93.50 | 94.04 |
| 8 | 84.33 | 84.87 | 85.41 | 85.95 | 86.49 | 87.03 | 87.57 | 88.11 | 88.65 | 89.19 | 89.73 | 90.27 | 90.81 | 91.35 | 91.89 | 92.43 | 92.97 | 93.51 | 94.05 |
| | 84.34 | 84.88 | 85.42 | 85.96 | 86.50 | 87.04 | 87.58 | 88.12 | 88.66 | 89.20 | 89.74 | 90.28 | 90.82 | 91.36 | 91.90 | 92.44 | 92.98 | 93.52 | 94.06 |
| 9 | 84.35 | 84.89 | 85.43 | 85.97 | 86.51 | 87.05 | 87.59 | 88.13 | 88.67 | 89.21 | 89.75 | 90.29 | 90.83 | 91.37 | 91.91 | 92.45 | 92.99 | 93.53 | 94.07 |
| | 84.36 | 84.90 | 85.44 | 85.98 | 86.52 | 87.06 | 87.60 | 88.14 | 88.68 | 89.22 | 89.76 | 90.30 | 90.84 | 91.38 | 91.92 | 92.46 | 93.00 | 93.54 | 94.08 |
| | 84.37 | 84.91 | 85.45 | 85.99 | 86.53 | 87.07 | 87.61 | 88.15 | 88.69 | 89.23 | 89.77 | 90.31 | 90.85 | 91.39 | 91.93 | 92.47 | 93.01 | 93.55 | 94.09 |
| 10 | 84.38 | 84.92 | 85.46 | 86.00 | 86.54 | 87.08 | 87.62 | 88.16 | 88.70 | 89.24 | 89.78 | 90.32 | 90.86 | 91.40 | 91.94 | 92.48 | 93.02 | 93.56 | 94.10 |
| | 84.39 | 84.93 | 85.47 | 86.01 | 86.55 | 87.09 | 87.63 | 88.17 | 88.71 | 89.25 | 89.79 | 90.33 | 90.87 | 91.41 | 91.95 | 92.49 | 93.03 | 93.57 | 94.11 |
| 11 | 84.40 | 84.94 | 85.48 | 86.02 | 86.56 | 87.10 | 87.64 | 88.18 | 88.72 | 89.26 | 89.80 | 90.34 | 90.88 | 91.42 | 91.96 | 92.50 | 93.04 | 93.58 | 94.12 |
| | 84.41 | 84.95 | 85.49 | 86.03 | 86.57 | 87.11 | 87.65 | 88.19 | 88.73 | 89.27 | 89.81 | 90.35 | 90.89 | 91.43 | 91.97 | 92.51 | 93.05 | 93.59 | 94.13 |
| 12 | 84.42 | 84.96 | 85.50 | 86.04 | 86.58 | 87.12 | 87.66 | 88.20 | 88.74 | 89.28 | 89.82 | 90.36 | 90.90 | 91.44 | 91.98 | 92.52 | 93.06 | 93.60 | 94.14 |
| | 84.43 | 84.97 | 85.51 | 86.05 | 86.59 | 87.13 | 87.67 | 88.21 | 88.75 | 89.29 | 89.83 | 90.37 | 90.91 | 91.45 | 91.99 | 92.53 | 93.07 | 93.61 | 94.15 |
| | 84.44 | 84.98 | 85.52 | 86.06 | 86.60 | 87.14 | 87.68 | 88.22 | 88.76 | 89.30 | 89.84 | 90.38 | 90.92 | 91.46 | 92.00 | 92.54 | 93.08 | 93.62 | 94.16 |
| 13 | 84.45 | 84.99 | 85.53 | 86.07 | 86.61 | 87.15 | 87.69 | 88.23 | 88.77 | 89.31 | 89.85 | 90.39 | 90.93 | 91.47 | 92.01 | 92.55 | 93.09 | 93.63 | 94.17 |
| | 84.46 | 85.00 | 85.54 | 86.08 | 86.62 | 87.16 | 87.70 | 88.24 | 88.78 | 89.32 | 89.86 | 90.40 | 90.94 | 91.48 | 92.02 | 92.56 | 93.10 | 93.64 | 94.18 |
| 14 | 84.47 | 85.01 | 85.55 | 86.09 | 86.63 | 87.17 | 87.71 | 88.25 | 88.79 | 89.33 | 89.87 | 90.41 | 90.95 | 91.49 | 92.03 | 92.57 | 93.11 | 93.65 | 94.19 |
| | 84.48 | 85.02 | 85.56 | 86.10 | 86.64 | 87.18 | 87.72 | 88.26 | 88.80 | 89.34 | 89.88 | 90.42 | 90.96 | 91.50 | 92.04 | 92.58 | 93.12 | 93.66 | 94.20 |
| 15 | 84.49 | 85.03 | 85.57 | 86.11 | 86.65 | 87.19 | 87.73 | 88.27 | 88.81 | 89.35 | 89.89 | 90.43 | 90.97 | 91.51 | 92.05 | 92.59 | 93.13 | 93.67 | 94.21 |
| | 84.50 | 85.04 | 85.58 | 86.12 | 86.66 | 87.20 | 87.74 | 88.28 | 88.82 | 89.36 | 89.90 | 90.44 | 90.98 | 91.52 | 92.06 | 92.60 | 93.14 | 93.68 | 94.22 |
| 16 | 84.51 | 85.05 | 85.59 | 86.13 | 86.67 | 87.21 | 87.75 | 88.29 | 88.83 | 89.37 | 89.91 | 90.45 | 90.99 | 91.53 | 92.07 | 92.61 | 93.15 | 93.69 | 94.23 |
| | 84.52 | 85.06 | 85.60 | 86.14 | 86.68 | 87.22 | 87.76 | 88.30 | 88.84 | 89.38 | 89.92 | 90.46 | 91.00 | 91.54 | 92.08 | 92.62 | 93.16 | 93.70 | 94.24 |
| | 84.53 | 85.07 | 85.61 | 86.15 | 86.69 | 87.23 | 87.77 | 88.31 | 88.85 | 89.39 | 89.93 | 90.47 | 91.01 | 91.55 | 92.09 | 92.63 | 93.17 | 93.71 | 94.25 |
| 17 | 84.54 | 85.08 | 85.62 | 86.16 | 86.70 | 87.24 | 87.78 | 88.32 | 88.86 | 89.40 | 89.94 | 90.48 | 91.02 | 91.56 | 92.10 | 92.64 | 93.18 | 93.72 | 94.26 |
| | 84.55 | 85.09 | 85.63 | 86.17 | 86.71 | 87.25 | 87.79 | 88.33 | 88.87 | 89.41 | 89.95 | 90.49 | 91.03 | 91.57 | 92.11 | 92.65 | 93.19 | 93.73 | 94.27 |
| 18 | 84.56 | 85.10 | 85.64 | 86.18 | 86.72 | 87.26 | 87.80 | 88.34 | 88.88 | 89.42 | 89.96 | 90.50 | 91.04 | 91.58 | 92.12 | 92.66 | 93.20 | 93.74 | 94.28 |
| | 84.57 | 85.11 | 85.65 | 86.19 | 86.73 | 87.27 | 87.81 | 88.35 | 88.89 | 89.43 | 89.97 | 90.51 | 91.05 | 91.59 | 92.13 | 92.67 | 93.21 | 93.75 | 94.29 |
| 19 | 84.58 | 85.12 | 85.66 | 86.20 | 86.74 | 87.28 | 87.82 | 88.36 | 88.90 | 89.44 | 89.98 | 90.52 | 91.06 | 91.60 | 92.14 | 92.68 | 93.22 | 93.76 | 94.30 |
| | 84.59 | 85.13 | 85.67 | 86.21 | 86.75 | 87.29 | 87.83 | 88.37 | 88.91 | 89.45 | 89.99 | 90.53 | 91.07 | 91.61 | 92.15 | 92.69 | 93.23 | 93.77 | 94.31 |
| 20 | 84.60 | 85.14 | 85.68 | 86.22 | 86.76 | 87.30 | 87.84 | 88.38 | 88.92 | 89.46 | 90.00 | 90.54 | 91.08 | 91.62 | 92.16 | 92.70 | 93.24 | 93.78 | 94.32 |
| | 84.61 | 85.15 | 85.69 | 86.23 | 86.77 | 87.31 | 87.85 | 88.39 | 88.93 | 89.47 | 90.01 | 90.55 | 91.09 | 91.63 | 92.17 | 92.71 | 93.25 | 93.79 | 94.33 |
| | 84.62 | 85.16 | 85.70 | 86.24 | 86.78 | 87.32 | 87.86 | 88.40 | 88.94 | 89.48 | 90.02 | 90.56 | 91.10 | 91.64 | 92.18 | 92.72 | 93.26 | 93.80 | 94.34 |
| 21 | 84.63 | 85.17 | 85.71 | 86.25 | 86.79 | 87.33 | 87.87 | 88.41 | 88.95 | 89.49 | 90.03 | 90.57 | 91.11 | 91.65 | 92.19 | 92.73 | 93.27 | 93.81 | 94.35 |
| | 84.64 | 85.18 | 85.72 | 86.26 | 86.80 | 87.34 | 87.88 | 88.42 | 88.96 | 89.50 | 90.04 | 90.58 | 91.12 | 91.66 | 92.20 | 92.74 | 93.28 | 93.82 | 94.36 |
| 22 | 84.65 | 85.19 | 85.73 | 86.27 | 86.81 | 87.35 | 87.89 | 88.43 | 88.97 | 89.51 | 90.05 | 90.59 | 91.13 | 91.67 | 92.21 | 92.75 | 93.29 | 93.83 | 94.37 |
| | 84.66 | 85.20 | 85.74 | 86.28 | 86.82 | 87.36 | 87.90 | 88.44 | 88.98 | 89.52 | 90.06 | 90.60 | 91.14 | 91.68 | 92.22 | 92.76 | 93.30 | 93.84 | 94.38 |
| 23 | 84.67 | 85.21 | 85.75 | 86.29 | 86.83 | 87.37 | 87.91 | 88.45 | 88.99 | 89.53 | 90.07 | 90.61 | 91.15 | 91.69 | 92.23 | 92.77 | 93.31 | 93.85 | 94.39 |
| | 84.68 | 85.22 | 85.76 | 86.30 | 86.84 | 87.38 | 87.92 | 88.46 | 89.00 | 89.54 | 90.08 | 90.62 | 91.16 | 91.70 | 92.24 | 92.78 | 93.32 | 93.86 | 94.40 |
| | 84.69 | 85.23 | 85.77 | 86.31 | 86.85 | 87.39 | 87.93 | 88.47 | 89.01 | 89.55 | 90.09 | 90.63 | 91.17 | 91.71 | 92.25 | 92.79 | 93.33 | 93.87 | 94.41 |

TABLE 95.—EQUIVALENTS OF REDUCED LEVELS IN METRES AND PICS (CUBITS) ON THE RODA (CAIRO) GAUGE.

| Pics. | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | Pics. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m. | m | m. | m. | m. | m. | m. | m. | m. | |
| 0 | 12·59 | 13·14 | 13·67 | 14·21 | 14·75 | 15·24 | 15·74 | 16·27 | 16·81 | 17·35 | 17·62 | 17·89 | 18·16 | 18·43 | 18·70 | 18·97 | 19·51 | 20·05 | 20·59 | 21·13 | 0 |
| 1 | 12·61 | 13·16 | 13·69 | 14·23 | 14·77 | 15·26 | 15·76 | 16·29 | 16·83 | 17·36 | 17·63 | 17·90 | 18·17 | 18·44 | 18·71 | 19·00 | 19·53 | 20·08 | 20·61 | 21·15 | 1 |
| 2 | 12·63 | 13·18 | 13·71 | 14·25 | 14·79 | 15·28 | 15·78 | 16·31 | 16·85 | 17·37 | 17·64 | 17·91 | 18·18 | 18·45 | 18·72 | 19·02 | 19·55 | 20·10 | 20·63 | 21·17 | 2 |
| 3 | 12·65 | 13·20 | 13·73 | 14·27 | 14·81 | 15·30 | 15·81 | 16·34 | 16·88 | 17·38 | 17·65 | 17·92 | 18·20 | 18·46 | 18·74 | 19·04 | 19·58 | 20·12 | 20·65 | 21·19 | 3 |
| 4 | 12·68 | 13·22 | 13·76 | 14·30 | 14·83 | 15·32 | 15·83 | 16·36 | 16·90 | 17·39 | 17·66 | 17·93 | 18·21 | 18·47 | 18·75 | 19·06 | 19·60 | 20·14 | 20·68 | 21·22 | 4 |
| 5 | 12·70 | 13·24 | 13·78 | 14·32 | 14·85 | 15·34 | 15·85 | 16·38 | 16·92 | 17·40 | 17·67 | 17·94 | 18·22 | 18·48 | 18·76 | 19·08 | 19·62 | 20·16 | 20·70 | 21·24 | 5 |
| 6 | 12·72 | 13·27 | 13·80 | 14·34 | 14·87 | 15·36 | 15·87 | 16·40 | 16·94 | 17·41 | 17·68 | 17·95 | 18·23 | 18·50 | 18·77 | 19·11 | 19·64 | 20·19 | 20·72 | 21·26 | 6 |
| 7 | 12·74 | 13·29 | 13·82 | 14·36 | 14·89 | 15·38 | 15·89 | 16·42 | 16·96 | 17·42 | 17·69 | 17·96 | 18·24 | 18·51 | 18·78 | 19·13 | 19·66 | 20·21 | 20·74 | 21·28 | 7 |
| 8 | 12·77 | 13·31 | 13·84 | 14·39 | 14·91 | 15·41 | 15·91 | 16·44 | 16·99 | 17·44 | 17·71 | 17·98 | 18·25 | 18·52 | 18·79 | 19·15 | 19·69 | 20·23 | 20·77 | 21·31 | 8 |
| 9 | 12·79 | 13·34 | 13·87 | 14·41 | 14·93 | 15·43 | 15·94 | 16·47 | 17·01 | 17·45 | 17·72 | 17·99 | 18·26 | 18·53 | 18·81 | 19·17 | 19·71 | 20·26 | 20·79 | 21·33 | 9 |
| 10 | 12·81 | 13·36 | 13·90 | 14·43 | 14·96 | 15·45 | 15·96 | 16·49 | 17·03 | 17·46 | 17·73 | 18·00 | 18·27 | 18·54 | 18·82 | 19·20 | 19·74 | 20·28 | 20·81 | 21·35 | 10 |
| 11 | 12·83 | 13·38 | 13·92 | 14·45 | 14·98 | 15·47 | 15·98 | 16·51 | 17·05 | 17·47 | 17·74 | 18·01 | 18·28 | 18·55 | 18·83 | 19·22 | 19·76 | 20·30 | 20·83 | 21·37 | 11 |
| 12 | 12·86 | 13·40 | 13·94 | 14·48 | 15·00 | 15·49 | 16·00 | 16·54 | 17·07 | 17·48 | 17·76 | 18·025 | 18·29 | 18·56 | 18·84 | 19·24 | 19·78 | 20·32 | 20·86 | 21·40 | 12 |
| 13 | 12·88 | 13·43 | 13·96 | 14·50 | 15·02 | 15·51 | 16·02 | 16·56 | 17·10 | 17·50 | 17·77 | 18·04 | 18·30 | 18·57 | 18·85 | 19·26 | 19·80 | 20·34 | 20·88 | 21·42 | 13 |
| Kirats 14 | 12·90 | 13·45 | 13·98 | 14·52 | 15·04 | 15·53 | 16·05 | 16·59 | 17·13 | 17·51 | 17·78 | 18·05 | 18·31 | 18·58 | 18·86 | 19·28 | 19·83 | 20·37 | 20·90 | 21·44 | 14 Kirats |
| 15 | 12·92 | 13·47 | 14·00 | 14·55 | 15·06 | 15·55 | 16·07 | 16·61 | 17·15 | 17·52 | 17·79 | 18·05 | 18·33 | 18·60 | 18·87 | 19·31 | 19·85 | 20·39 | 20·92 | ... | 15 |
| 16 | 12·95 | 13·49 | 14·03 | 14·57 | 15·08 | 15·57 | 16·09 | 16·63 | 17·17 | 17·53 | 17·80 | 18·07 | 18·34 | 18·61 | 18·88 | 19·33 | 19·87 | 20·41 | 20·95 | ... | 16 |
| 17 | 12·97 | 13·51 | 14·05 | 14·59 | 15·10 | 15·59 | 16·11 | 16·65 | 17·19 | 17·54 | 17·81 | 18·08 | 18·35 | 18·62 | 18·89 | 19·35 | 19·89 | 20·44 | 20·97 | ... | 17 |
| 18 | 12·99 | 13·53 | 14·07 | 14·61 | 15·12 | 15·61 | 16·13 | 16·68 | 17·22 | 17·55 | 17·82 | 18·09 | 18·36 | 18·63 | 18·90 | 19·37 | 19·92 | 20·46 | 20·99 | ... | 18 |
| 19 | 13·01 | 13·55 | 14·09 | 14·64 | 15·14 | 15·64 | 16·16 | 16·70 | 17·24 | 17·56 | 17·83 | 18·10 | 18·37 | 18·64 | 18·91 | 19·39 | 19·94 | 20·48 | 21·01 | ... | 19 |
| 20 | 13·04 | 13·58 | 14·11 | 14·66 | 15·16 | 15·66 | 16·18 | 17·72 | 17·26 | 17·57 | 17·84 | 18·11 | 18·39 | 18·66 | 18·92 | 19·42 | 19·96 | 20·50 | 21·04 | ... | 20 |
| 21 | 13·06 | 13·60 | 14·14 | 14·68 | 15·18 | 15·68 | 16·20 | 16·74 | 17·29 | 17·58 | 17·85 | 18·13 | 18·40 | 18·67 | 18·94 | 19·44 | 19·98 | 20·52 | 21·06 | .. | 21 |
| 22 | 13·08 | 13·62 | 14·16 | 14·71 | 15·20 | 15·70 | 16·22 | 16·76 | 17·31 | 17·60 | 17·86 | 18·14 | 18·41 | 18·68 | 18·95 | 19·46 | 20·01 | 20·55 | 21·08 | ... | 22 |
| 23 | 13·10 | 13·64 | 14·18 | 14·73 | 15·22 | 15·72 | 16·25 | 16·78 | 17·33 | 17·61 | 17·88 | 18·15 | 18·42 | 18·69 | 18·96 | 19·49 | 20·03 | 20·57 | 21·10 | ... | 23 |
| 24 | 13·14 | 13·67 | 14·21 | 14·75 | 15·24 | 15·74 | 16·27 | 16·81 | 17·35 | 17·62 | 17·89 | 18·16 | 18·43 | 18·70 | 18·97 | 19·51 | 20·05 | 20·59 | 21·13 | ... | 24 |

TABLE 96.—TEN-DAY MEAN GAUGE READINGS ON THE UPPER NILE FOR 1912.
(In metres.)

| Months. | | Mongalla. | Ghaba Shambé. | Doleib Hill. | Malakal. | Omdurman. | Kamlin. | Khashm el Girba. | Main Nile at Tamaniat. |
|---|---|---|---|---|---|---|---|---|---|
| January | 1–10 | 11·13 | 11·17 | 11·90 | 10·91 | 11·63 | 11·11 | 10·36 | |
| | 11–20 | 10·99 | 11·13 | 11·67 | 10·68 | 11·39 | 10·92 | 10·29 | |
| | 21–31 | 10·91 | 11·10 | 11·48 | 10·51 | 11·18 | 10·80 | 10·23 | |
| February | 1–10 | 10·87 | 11·03 | 11·31 | 10·35 | 10·98 | 10·66 | 10·16 | |
| | 11–20 | 10·86 | 10·90 | 11·18 | 10·23 | 10·84 | 10·54 | 10·11 | |
| | 21–29 | 10·84 | 10·80 | 11·10 | 10·16 | 10·68 | 10·38 | 10·07 | |
| March | 1–10 | 10·78 | 10·74 | 11·00 | 10·06 | 10·61 | 10·31 | 10·03 | |
| | 11–20 | 10·74 | 10·66 | 10·88 | 9·95 | 10·52 | 10·20 | | |
| | 21–31 | 10·80 | 10·60 | 10·82 | 9·89 | 10·40 | 10·11 | | |
| April | 1–10 | 10·84 | 10·57 | 10·74 | 9·82 | 10·32 | 10·01 | | |
| | 11–20 | 10·81 | 10·53 | 10·79 | 9·85 | 10·23 | 9·93 | | |
| | 21–30 | 10·90 | 10·51 | 10·65 | 9·73 | 10·21 | 9·90 | | |
| May | 1–10 | 10·86 | 10·52 | 10·51 | 9·60 | 10·17 | 9·81 | | |
| | 11–20 | 10·91 | 10·53 | 10·53 | 9·61 | 10·04 | 9·72 | | |
| | 21–31 | 11·11 | 10·61 | 10·63 | 9·69 | 9·93 | 9·69 | ... | 9·65 |
| June | 1–10 | 10·86 | 10·65 | 10·92 | 9·94 | 9·92 | 9·91 | ... | 9·67 |
| | 11–20 | 10·97 | 10·73 | 11·19 | 10·05 | 10·12 | 10·42 | ... | 9·99 |
| | 21–30 | 11·09 | 10·72 | 11·65 | 10·53 | 11·06 | 10·65 | 14·79 | 10·80 |
| July | 1–10 | 11·19 | 10·81 | 11·95 | 10·84 | 11·53 | 11·80 | 12·32 | 11·30 |
| | 11–20 | 11·72 | 10·83 | 12·16 | 11·08 | 12·11 | 12·88 | 12·29 | 11·84 |
| | 21–31 | 11·61 | 10·95 | 12·45 | 11·35 | 13·75 | 15·40 | 13·65 | 13·51 |
| August | 1–10 | 11·81 | 11·03 | 12·79 | 11·59 | 14·75 | 17·03 | 14·34 | 14·70 |
| | 11–20 | 12·14 | 11·07 | 13·07 | 11·82 | 15·26 | 16·96 | 14·28 | 15·39 |
| | 21–31 | 11·98 | 11·17 | 13·25 | 11·98 | 15·40 | 17·32 | 14·23 | 15·51 |
| September | 1–10 | 12·16 | 11·21 | 13·40 | 12·10 | 15·21 | 16·48 | 13·98 | 15·30 |
| | 11–20 | 12·42 | 11·33 | 13·49 | 12·19 | 14·91 | 16·32 | 13·33 | 14·94 |
| | 21–30 | 11·72 | 11·36 | 13·62 | 12·28 | 14·51 | 15·39 | 12·20 | 14·63 |
| October | 1–10 | 11·54 | 11·39 | 13·66 | 12·33 | 13·71 | 14·03 | 11·56 | 13·60 |
| | 11–20 | 11·48 | 11·46 | 13·47 | 12·28 | 13·09 | 12·10 | 11·11 | 12·99 |
| | 21–31 | 11·30 | 11·51 | 13·66 | 12·20 | 12·74 | 12·70 | 11·17 | 12·57 |

TABLE 97.—READINGS OF GAUGES ON THE UPPER NILE NOT REGULARLY RECORDED, 1912. (In metres.)

| | | |
|---|---|---|
| *Zeraf Mouth*— | | |
| August | 13 | 12·19 |
| | 29 | 12·40 |
| September | 16 | 12·57 |
| | 29 | 12·67 |
| *Khor Yergol*— | | |
| August | 28 | 13·88 |
| *Lake No*— | | |
| August | 1 | 13·67 |
| | 11 | 13·70 |
| | 20 | 13·78 |
| | 27 | 13·82 |
| September | 3 | 13·84 |
| *Buffalo Cape*— | | |
| August | 11 | 11·46 |
| | 20 | 11·47 |
| | 27 | 11·50 |
| September | 4 | 11·50 |
| | 12 | 11·53 |
| | 24 | 11·53 |
| *Hillet Nuer*— | | |
| August | 2 | 10·92 |
| | 8 | 10·96 |
| | 26 | 11·02 |
| September | 4 | 11·04 |
| *Head of Zeraf Cut*— | | |
| August | 7 | 11·10 |
| September | 27 | (11·70)? |
| *Ghaba el Inderab*— | | |
| August | 7 | 11·18 |
| *Zeraf Kilo* 50 from the mouth— | | |
| September | 29 | 14·74 |
| *Zeraf Kilo* 100— | | |
| September | 29 | 16·27 |
| *Zeraf Kilo* 189— | | |
| September | 3 | 20·49 |
| *Zeraf Kilo* 235— | | |
| September | 3 | 22·62 |
| | 28 | 22·80 |
| *Zeraf Kilo* 266— | | |
| September | 3 | 26·60 |
| *Tail of Zeraf Cut*— | | |
| August | 7 | 27·19 |
| September | 3 | 27·40 |
| | 27 | 27·43 |
| *Lake No*— | | |
| February | 9 | 13·39 |
| | 11 | 13·58 |
| | 12 | 13·58 |
| | 15 | 13·57 |
| | 19 | 13·56 |
| March | 7 | 13·53 |
| May | 22 | 13·26 |
| *Buffalo Cape*— | | |
| May | 22 | 11·11 |

26. **Discharge Tables for the Nile Gauges.**—The devotion which Mr P. M. Tottenham, Inspector General of the Sudan Irrigation Service, has given to the subject of discharges, has thrown a flood of light on the subject. We have discharge tables for the outlets of Lakes Victoria and Albert, prepared by Mr Craig, which give a good idea of the behaviour of the upper waters of the White Nile. We have further discharge tables for the Mongalla gauge on the Albert Nile at its entrance into the Sudd region ; for the Doleib Hill gauge at the tail of the Sobat, which is unfortunately in a backwater, but for which a good working table allowing for a rising and falling river has been prepared by Mr Shakerley ; for the Malakal gauge at the beginning of the White Nile; for the Kamlin gauge at the tail of the Blue Nile above the reach of backwater ; and for

the Tamaniat gauge at the head of the Main Nile downstream of Omdurman. The Mongalla and Malakal tables are good, reliable tables. The tail of the Blue Nile will always be a difficult reach to prepare a working table for. If the Blue Nile flood is high and the White Nile flood poor and ill-maintained, the Blue Nile scours out its bed considerably and deposits the silt in the Main Nile downstream of Omdurman. If, on the contrary, the Blue Nile is poor and the White Nile well maintained, the tail reach of the Blue Nile is filled with silt and the Main Nile is scoured out. We have therefore given the table prepared for 1911 and another for 1912 for the Kamlin gauge. These tables will have to be prepared for a number of years and notably for some very high year, before a good working table, generally applicable, can be secured.

We have a rough approximative table for the Atbara at Khashm el Girba, and for the Abu Hashim gauge on the Dinder. The Rahad allows too much of its waters to escape over the plains it traverses to be provided with a working table.

We have a good discharge table for Wadi Halfa, which has to be used with judgment. If the river is rising fairly rapidly, take the discharge of the gauge 10 centimetres higher, and when falling 10 centimetres lower. For such gauges, five-day means can be used with advantage. The Aswan discharge table gives higher figures than those in the Second edition. The scouring out of the bed of the river downstream of the dam by the heavy quantities of clear water issuing from the reservoir in winter and summer has changed the character of the river, and, gauge for gauge, we have higher discharges now than we had previous to 1903.

The discharge table for Aswan can be used approximatively for Cairo during high floods when the Delta Barrages are open, if we make R.L. 12·50 take the place of R.L. 85·00.

We have in addition a series of interesting discharges on the Albert Nile, the Zeraf, Sobat, and Gazelle rivers. These discharges show clearly the carrying capacity of the Albert Nile as it traverses the Sudd region has been increased steadily by scour since 1900 when the Sudd clearing operations began. The discharges given in Table 110 are measured discharges, taken when the Sobat was low, and when there was no backwater at No. Discharges taken in flood, when the Sobat is throwing No into a backwater, are of no value.

It must not be imagined for a single instant that these long lists of figures are dead things. In the hands of competent and originally minded engineers they have within them as great a potency of life as the fabled dragon's teeth, and, when sown up and down, may chance to spring up armed men. Without them no grasp can ever be had of the behaviour of the Upper Nile and its tributaries.

We are of opinion that on all discharge tables referred to gauges, the

year should be carefully stated during which the observations were made from which the tables have been calculated. A high flood scours out the bed of the river and a low flood silts it up. The difference between 1892 (a very high flood) and 1893 (a low flood) was 1 metre over hundreds of kilometres of the river.

TABLE 98.—DISCHARGE TABLE OF THE VICTORIA NILE AT THE RIPON FALLS.
(Cubic metres per second.)

| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0·0 | 380 | 383 | 386 | 389 | 392 | 395 | 398 | 401 | 404 | 407 |
| ·1 | 410 | 414 | 418 | 422 | 426 | 430 | 434 | 438 | 442 | 446 |
| ·2 | 450 | 453 | 456 | 459 | 462 | 465 | 468 | 471 | 474 | 477 |
| ·3 | 480 | 484 | 488 | 492 | 496 | 500 | 504 | 508 | 512 | 516 |
| ·4 | 520 | 523 | 526 | 529 | 532 | 535 | 538 | 541 | 544 | 547 |
| ·5 | 550 | 553 | 556 | 559 | 562 | 565 | 568 | 571 | 574 | 577 |
| ·6 | 580 | 584 | 588 | 592 | 596 | 600 | 604 | 608 | 612 | 616 |
| ·7 | 620 | 624 | 628 | 632 | 636 | 640 | 644 | 648 | 652 | 656 |
| ·8 | 660 | 664 | 668 | 672 | 676 | 680 | 684 | 688 | 692 | 696 |
| ·9 | 700 | 704 | 708 | 712 | 716 | 720 | 724 | 728 | 732 | 736 |
| 1·0 | 740 | 744 | 748 | 752 | 756 | 760 | 764 | 768 | 772 | 776 |
| ·1 | 780 | 784 | 788 | 792 | 796 | 800 | 804 | 808 | 812 | 816 |
| 2 | 820 | 824 | 828 | 832 | 836 | 840 | 844 | 848 | 852 | 856 |
| ·3 | 860 | 864 | 868 | 872 | 876 | 880 | 884 | 888 | 892 | 896 |
| ·4 | 900 | 905 | 910 | 915 | 920 | 925 | 930 | 935 | 940 | 945 |
| ·5 | 950 | 954 | 958 | 962 | 966 | 970 | 974 | 978 | 982 | 986 |
| ·6 | 990 | 995 | 1000 | 1005 | 1010 | 1015 | 1020 | 1025 | 1030 | 1035 |
| ·7 | 1040 | 1045 | 1050 | 1055 | 1060 | 1065 | 1070 | 1075 | 1080 | 1085 |
| ·8 | 1090 | 1095 | 1100 | 1105 | 1110 | 1115 | 1120 | 1125 | 1130 | 1135 |
| ·9 | 1140 | 1145 | 1150 | 1155 | 1160 | 1165 | 1170 | 1175 | 1180 | 1185 |
| 2·0 | 1190 | | | | | | | | | |

[TABLE

TABLE 99.—DISCHARGE TABLE OF THE ALBERT NILE AT WADELAI.
(Cubic metres per second.)

| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0·0 | 520 | 522 | 525 | 527 | 530 | 532 | 534 | 537 | 539 | 542 |
| ·1 | 544 | 546 | 549 | 551 | 554 | 556 | 558 | 561 | 563 | 566 |
| ·2 | 568 | 570 | 573 | 575 | 578 | 580 | 582 | 585 | 587 | 590 |
| ·3 | 592 | 594 | 597 | 599 | 602 | 604 | 606 | 609 | 611 | 614 |
| ·4 | 616 | 618 | 621 | 623 | 626 | 628 | 630 | 633 | 635 | 638 |
| ·5 | 640 | 642 | 645 | 647 | 650 | 652 | 654 | 657 | 659 | 662 |
| ·6 | 668 | 671 | 674 | 676 | 679 | 682 | 685 | 688 | 690 | 693 |
| ·7 | 696 | 699 | 702 | 704 | 707 | 710 | 713 | 716 | 718 | 721 |
| ·8 | 724 | 727 | 730 | 732 | 735 | 738 | 741 | 744 | 746 | 749 |
| ·9 | 752 | 755 | 758 | 760 | 763 | 766 | 769 | 772 | 774 | 777 |
| 1·0 | 780 | 783 | 786 | 789 | 792 | 795 | 798 | 801 | 804 | 807 |
| ·1 | 810 | 813 | 816 | 819 | 822 | 825 | 828 | 831 | 834 | 837 |
| ·2 | 840 | 843 | 846 | 849 | 852 | 855 | 858 | 861 | 864 | 867 |
| ·3 | 870 | 873 | 876 | 879 | 882 | 885 | 888 | 891 | 894 | 897 |
| ·4 | 900 | 903 | 906 | 909 | 912 | 915 | 918 | 921 | 924 | 927 |
| ·5 | 930 | 933 | 936 | 940 | 943 | 946 | 949 | 952 | 956 | 959 |
| ·6 | 962 | 965 | 968 | 972 | 975 | 978 | 981 | 984 | 988 | 991 |
| ·7 | 994 | 997 | 1000 | 1004 | 1007 | 1010 | 1013 | 1016 | 1020 | 1023 |
| ·8 | 1026 | 1029 | 1032 | 1036 | 1039 | 1042 | 1045 | 1048 | 1052 | 1055 |
| ·9 | 1058 | 1061 | 1064 | 1068 | 1071 | 1074 | 1077 | 1080 | 1084 | 1087 |
| 2·0 | 1090 | 1091 | 1093 | 1094 | 1096 | 1097 | 1098 | 1100 | 1101 | 1103 |
| ·1 | 1104 | 1105 | 1107 | 1108 | 1110 | 1111 | 1112 | 1114 | 1115 | 1117 |
| ·2 | 1118 | 1119 | 1121 | 1122 | 1124 | 1125 | 1126 | 1128 | 1129 | 1131 |
| ·3 | 1132 | 1133 | 1135 | 1136 | 1138 | 1139 | 1140 | 1142 | 1143 | 1145 |
| ·4 | 1146 | 1147 | 1149 | 1150 | 1152 | 1153 | 1154 | 1156 | 1157 | 1159 |
| 2·5 | 1160 | 1161 | 1163 | 1164 | 1166 | 1167 | 1168 | 1170 | 1171 | 1173 |

TABLE 100.—DISCHARGE TABLE OF THE ALBERT NILE AT MONGALLA.
(Cubic metres per second.)

| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10·5 | 460 | 461 | 463 | 465 | 466 | 468 | 469 | 471 | 473 | 475 |
| ·6 | 477 | 479 | 481 | 483 | 485 | 488 | 490 | 492 | 495 | 497 |
| ·7 | 500 | 502 | 505 | 507 | 510 | 512 | 515 | 517 | 520 | 522 |
| 8 | 525 | 528 | 531 | 534 | 537 | 540 | 543 | 546 | 549 | 552 |
| ·9 | 555 | 558 | 561 | 564 | 567 | 570 | 573 | 576 | 579 | 582 |
| 11·0 | 585 | 588 | 592 | 595 | 599 | 602 | 606 | 609 | 613 | 616 |
| ·1 | 620 | 624 | 628 | 632 | 636 | 640 | 644 | 648 | 652 | 656 |
| ·2 | 660 | 664 | 668 | 672 | 676 | 680 | 684 | 688 | 692 | 696 |
| ·3 | 700 | 704 | 709 | 713 | 718 | 722 | 727 | 731 | 736 | 740 |
| ·4 | 745 | 750 | 755 | 760 | 765 | 770 | 775 | 780 | 785 | 790 |
| ·5 | 795 | 800 | 805 | 810 | 815 | 820 | 825 | 830 | 835 | 840 |
| ·6 | 845 | 851 | 857 | 863 | 870 | 875 | 881 | 887 | 893 | 899 |
| ·7 | 905 | 911 | 917 | 923 | 929 | 935 | 941 | 947 | 953 | 959 |
| ·8 | 965 | 971 | 978 | 984 | 991 | 997 | 1004 | 1010 | 1017 | 1023 |
| ·9 | 1030 | 1037 | 1044 | 1051 | 1058 | 1065 | 1072 | 1079 | 1086 | 1093 |
| 12·0 | 1100 | 1110 | 1119 | 1129 | 1138 | 1148 | 1157 | 1167 | 1178 | 1186 |
| ·1 | 1195 | 1205 | 1214 | 1224 | 1233 | 1243 | 1252 | 1262 | 1271 | 1281 |
| ·2 | 1290 | 1300 | 1309 | 1319 | 1328 | 1338 | 1347 | 1357 | 1366 | 1375 |
| ·3 | 1385 | 1395 | 1404 | 1414 | 1423 | 1435 | 1442 | 1452 | 1461 | 1471 |
| ·4 | 1480 | 1490 | 1499 | 1509 | 1518 | 1528 | 1537 | 1547 | 1556 | 1566 |
| ·5 | 1575 | 1585 | 1595 | 1604 | 1614 | 1623 | 1633 | 1642 | 1652 | 1661 |
| ·6 | 1670 | 1680 | 1689 | 1699 | 1708 | 1718 | 1727 | 1737 | 1746 | 1756 |
| ·7 | 1765 | 1775 | 1784 | 1794 | 1803 | 1813 | 1822 | 1832 | 1841 | 1851 |
| ·8 | 1860 | 1870 | 1879 | 1889 | 1898 | 1908 | 1917 | 1927 | 1936 | 1946 |
| ·9 | 1955 | 1965 | 1974 | 1983 | 1993 | 2002 | 2012 | 2021 | 2031 | 2040 |
| 13·0 | 2050 | 2060 | 2069 | 2079 | 2088 | 2098 | 2107 | 2117 | 2126 | 2136 |
| ·1 | 2145 | 2155 | 2164 | 2174 | 2183 | 2193 | 2202 | 2212 | 2221 | 2231 |
| ·2 | 2240 | 2250 | 2259 | 2268 | 2278 | 2287 | 2297 | 2306 | 2316 | 2325 |
| ·3 | 2335 | 2345 | 2354 | 2364 | 2373 | 2383 | 2392 | 2402 | 2411 | 2420 |
| ·4 | 2430 | 2440 | 2449 | 2459 | 2468 | 2478 | 2487 | 2497 | 2506 | 2516 |
| 13·5 | 2525 | 2535 | 2544 | 2554 | 2563 | 2573 | 2582 | 2592 | 2601 | 2611 |

R.L. of zero, 431·13.

TABLE 101.—DISCHARGE TABLE OF THE SOBAT AT DOLEIB HILL.
(Cubic metres per second.)

| Gauge Reading. | Rising. | Falling. | Gauge Reading. | Rising. | Falling. | Gauge Reading. | Rising. | Falling. |
|---|---|---|---|---|---|---|---|---|
| 10·50 | 0 | 0 | 12·00 | 398 | 191 | 13·00 | 650 | 405 |
| 10·75 | 53 | 30 | 12·25 | 466 | 225 | 13·25 | 708 | 500 |
| 11·00 | 112 | 59 | 12·50 | 530 | 268 | 13·50 | 770 | 650 |
| 11·25 | 176 | 92 | 12·75 | 590 | 328 | 13·75 | 848 | 848 |
| 11·50 | 252 | 122 | | | | 14·00 | 938 | 938 |
| 11·75 | 328 | 156 | | | | 14·25 | 1038 | 1038 |

This gauge is in a backwater. R.L. of zero, 375·43.

TABLE 102.—DISCHARGE TABLE OF THE WHITE NILE AT MALAKAL.
(Cubic metres per second.)

| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 9·0 | | | | | | | | | | |
| ·1 | | | | | | | | | | |
| ·2 | | | | | | | | | | |
| ·3 | | | | | | | | | | |
| ·4 | | | | | | | | | | |
| ·5 | 450 | 451 | 452 | 453 | 454 | 455 | 457 | 459 | 461 | 463 |
| ·6 | 465 | 466 | 467 | 468 | 469 | 470 | 472 | 474 | 476 | 478 |
| ·7 | 480 | 482 | 484 | 486 | 488 | 490 | 492 | 494 | 496 | 498 |
| ·8 | 500 | 502 | 504 | 506 | 508 | 510 | 512 | 514 | 516 | 518 |
| ·9 | 520 | 522 | 524 | 526 | 528 | 530 | 532 | 534 | 536 | 538 |
| 10·0 | 540 | 542 | 544 | 546 | 548 | 550 | 552 | 554 | 556 | 558 |
| ·1 | 560 | 562 | 564 | 566 | 568 | 570 | 572 | 574 | 576 | 578 |
| ·2 | 580 | 582 | 585 | 587 | 590 | 592 | 595 | 597 | 600 | 602 |
| ·3 | 605 | 607 | 610 | 612 | 615 | 617 | 620 | 622 | 625 | 627 |
| ·4 | 630 | 632 | 635 | 637 | 640 | 642 | 645 | 647 | 650 | 652 |
| ·5 | 655 | 657 | 660 | 662 | 665 | 667 | 670 | 672 | 675 | 677 |
| ·6 | 680 | 682 | 685 | 687 | 690 | 692 | 695 | 697 | 700 | 702 |
| ·7 | 705 | 707 | 710 | 712 | 715 | 717 | 720 | 722 | 725 | 727 |
| ·8 | 730 | 733 | 736 | 739 | 742 | 745 | 748 | 751 | 754 | 757 |
| ·9 | 760 | 763 | 767 | 770 | 774 | 777 | 781 | 784 | 788 | 791 |
| 11·0 | 795 | 798 | 802 | 805 | 809 | 812 | 816 | 819 | 823 | 826 |
| ·1 | 830 | 833 | 837 | 840 | 844 | 847 | 851 | 854 | 858 | 861 |
| ·2 | 865 | 868 | 872 | 875 | 879 | 882 | 886 | 889 | 893 | 896 |
| ·3 | 900 | 903 | 906 | 909 | 912 | 915 | 918 | 921 | 924 | 927 |
| ·4 | 930 | 932 | 935 | 937 | 940 | 942 | 945 | 947 | 950 | 952 |
| ·5 | 955 | 958 | 962 | 965 | 969 | 972 | 976 | 979 | 983 | 986 |
| ·6 | 990 | 993 | 997 | 1000 | 1004 | 1007 | 1011 | 1014 | 1018 | 1021 |
| ·7 | 1025 | 1028 | 1032 | 1035 | 1039 | 1042 | 1046 | 1049 | 1053 | 1056 |
| ·8 | 1060 | 1063 | 1067 | 1070 | 1074 | 1077 | 1081 | 1084 | 1088 | 1091 |
| ·9 | 1095 | 1098 | 1102 | 1105 | 1108 | 1112 | 1115 | 1119 | 1122 | 1126 |
| 12·0 | 1130 | 1133 | 1137 | 1140 | 1144 | 1147 | 1151 | 1154 | 1158 | 1161 |
| ·1 | 1165 | 1169 | 1173 | 1177 | 1181 | 1185 | 1189 | 1193 | 1197 | 1201 |
| ·2 | 1205 | 1209 | 1213 | 1217 | 1221 | 1225 | 1229 | 1233 | 1237 | 1241 |
| ·3 | 1245 | 1250 | 1255 | 1260 | 1265 | 1270 | 1275 | 1280 | 1285 | 1290 |
| ·4 | 1295 | 1300 | 1305 | 1310 | 1315 | 1320 | 1325 | 1330 | 1335 | 1340 |
| ·5 | 1345 | 1350 | 1356 | 1361 | 1367 | 1372 | 1378 | 1383 | 1389 | 1394 |
| ·6 | 1400 | 1406 | 1412 | 1418 | 1424 | 1430 | 1436 | 1442 | 1448 | 1454 |
| ·7 | 1460 | 1467 | 1474 | 1481 | 1488 | 1495 | 1502 | 1509 | 1516 | 1523 |
| ·8 | 1530 | 1538 | 1546 | 1554 | 1562 | 1570 | 1578 | 1586 | 1594 | 1602 |
| ·9 | 1610 | 1619 | 1628 | 1637 | 1646 | 1655 | 1664 | 1673 | 1682 | 1691 |
| 13·0 | 1700 | | | | | | | | | |

R.L. of zero, 375·00 metres.

TABLE 103.—DISCHARGE TABLE OF THE BLUE NILE FOR KAMLIN, 1912.
(Cubic metres per second.)

| Gauge. | Rising Nile. Discharge. | Stationary and Falling Nile. Discharge. | Gauge. | Rising Nile. Discharge. | Stationary and Falling Nile. Discharge. |
|---|---|---|---|---|---|
| 11·80 | 820 | ... | 15·00 | 3430 | 3097 |
| ·90 | 870 | ... | ·10 | 3540 | 3102 |
| 12·00 | 922 | ... | ·20 | 3650 | 3310 |
| ·10 | 975 | ... | ·30 | 3760 | 3419 |
| ·20 | 1028 | ... | ·40 | 3870 | 3528 |
| ·30 | 1083 | ... | ·50 | 3984 | 3638 |
| ·40 | 1140 | ... | ·60 | 4098 | 3752 |
| ·50 | 1200 | ... | ·70 | 4213 | 3867 |
| ·60 | 1262 | ... | ·80 | 4330 | 3990 |
| ·70 | 1326 | ... | ·90 | 4449 | 4115 |
| ·80 | 1395 | 1322 | 16·00 | 4570 | 4242 |
| ·90 | 1465 | 1380 | ·10 | 4692 | 4371 |
| 13·00 | 1538 | 1442 | ·20 | 4818 | 4502 |
| ·10 | 1616 | 1508 | ·30 | 4948 | 4635 |
| ·20 | 1698 | 1575 | ·40 | 5080 | 4785 |
| ·30 | 1780 | 1648 | ·50 | 5225 | 4940 |
| ·40 | 1867 | 1720 | ·60 | 5372 | 5100 |
| ·50 | 1955 | 1795 | ·70 | 5530 | 5260 |
| ·60 | 2045 | 1870 | ·80 | 5690 | 5422 |
| ·70 | 2136 | 1948 | ·90 | 5850 | 5587 |
| ·80 | 2228 | 2028 | 17·00 | 6013 | 5755 |
| ·90 | 2322 | 2108 | ·10 | 6284 | 5927 |
| 14·00 | 2417 | 2188 | ·20 | 6355 | 6104 |
| ·10 | 2513 | 2270 | ·30 | 6530 | 6288 |
| ·20 | 2610 | 2352 | ·40 | 6717 | 6475 |
| ·30 | 2710 | 2435 | ·50 | 6917 | 6667 |
| ·40 | 2810 | 2520 | | | |
| ·50 | 2911 | 2608 | | | |
| ·60 | 3013 | 2698 | | | |
| ·70 | 3116 | 2790 | | | |
| ·80 | 3219 | 2890 | | | |
| ·90 | 3322 | 2992 | | | |

TABLE 104.—BLUE NILE DISCHARGE TABLE, 1911, FOR KAMLIN GAUGE.
(Cubic metres per second.)

| Cent. / Met. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10·0 | 70 | 73 | 76 | 79 | 82 | 85 | 88 | 91 | 94 | 97 |
| ·1 | 100 | 103 | 106 | 109 | 112 | 115 | 118 | 121 | 124 | 127 |
| ·2 | 130 | 133 | 136 | 139 | 142 | 145 | 148 | 151 | 154 | 157 |
| ·3 | 160 | 163 | 166 | 169 | 172 | 175 | 178 | 181 | 184 | 187 |
| ·4 | 190 | 194 | 198 | 202 | 206 | 210 | 214 | 218 | 222 | 226 |
| ·5 | 230 | 233 | 236 | 239 | 242 | 245 | 248 | 251 | 254 | 257 |
| ·6 | 260 | 264 | 268 | 272 | 276 | 280 | 284 | 288 | 292 | 296 |
| ·7 | 300 | 304 | 308 | 312 | 316 | 320 | 324 | 328 | 332 | 336 |
| ·8 | 340 | 344 | 348 | 352 | 356 | 360 | 364 | 368 | 372 | 376 |
| ·9 | 380 | 384 | 388 | 392 | 396 | 400 | 404 | 408 | 412 | 416 |
| 11·0 | 420 | 424 | 428 | 432 | 436 | 440 | 444 | 448 | 452 | 456 |
| ·1 | 460 | 464 | 468 | 472 | 474 | 478 | 482 | 486 | 492 | 496 |
| ·2 | 500 | 505 | 510 | 515 | 520 | 525 | 530 | 535 | 540 | 545 |
| ·3 | 550 | 555 | 560 | 565 | 570 | 575 | 580 | 585 | 590 | 595 |
| ·4 | 600 | 605 | 610 | 615 | 620 | 625 | 630 | 635 | 640 | 645 |
| ·5 | 650 | 655 | 660 | 665 | 670 | 675 | 680 | 685 | 690 | 695 |
| ·6 | 700 | 705 | 710 | 715 | 720 | 725 | 730 | 735 | 740 | 745 |
| ·7 | 750 | 756 | 762 | 768 | 774 | 780 | 786 | 792 | 798 | 804 |
| ·8 | 810 | 816 | 822 | 828 | 834 | 840 | 846 | 852 | 858 | 864 |
| ·9 | 870 | 876 | 882 | 888 | 894 | 900 | 906 | 912 | 918 | 924 |
| 12·0 | 930 | 936 | 942 | 948 | 754 | 960 | 966 | 972 | 978 | 984 |
| ·1 | 990 | 996 | 1002 | 1008 | 1014 | 1020 | 1026 | 1032 | 1038 | 1044 |
| ·2 | 1050 | 1056 | 1062 | 1068 | 1074 | 1080 | 1086 | 1092 | 1098 | 1104 |
| ·3 | 1110 | 1117 | 1124 | 1131 | 1138 | 1145 | 1152 | 1159 | 1166 | 1173 |
| ·4 | 1180 | 1187 | 1194 | 1201 | 1208 | 1215 | 1222 | 1229 | 1236 | 1243 |
| ·5 | 1250 | 1258 | 1266 | 1274 | 1282 | 1290 | 1298 | 1306 | 1314 | 1322 |
| ·6 | 1330 | 1338 | 1346 | 1354 | 1362 | 1370 | 1378 | 1386 | 1394 | 1402 |
| ·7 | 1410 | 1418 | 1426 | 1434 | 1442 | 1450 | 1458 | 1466 | 1474 | 1482 |
| ·8 | 1490 | 1498 | 1506 | 1514 | 1522 | 1530 | 1538 | 1546 | 1554 | 1562 |
| ·9 | 1570 | 1578 | 1586 | 1594 | 1602 | 1610 | 1618 | 1626 | 1634 | 1642 |
| 13·0 | 1650 | 1658 | 1666 | 1674 | 1682 | 1690 | 1698 | 1706 | 1714 | 1722 |
| ·1 | 1730 | 1738 | 1746 | 1754 | 1762 | 1770 | 1778 | 1786 | 1794 | 1802 |
| ·2 | 1810 | 1818 | 1826 | 1834 | 1842 | 1850 | 1858 | 1866 | 1874 | 1882 |
| ·3 | 1890 | 1898 | 1906 | 1914 | 1922 | 1930 | 1938 | 1946 | 1954 | 1962 |
| ·4 | 1970 | 1978 | 1986 | 1994 | 2002 | 2010 | 2018 | 2026 | 2034 | 2042 |
| ·5 | 2050 | 2059 | 2068 | 2077 | 2086 | 2095 | 2104 | 2113 | 2122 | 2131 |
| ·6 | 2140 | 2149 | 2158 | 2167 | 2176 | 2185 | 2194 | 2203 | 2212 | 2221 |
| ·7 | 2230 | 2239 | 2248 | 2257 | 2266 | 2275 | 2284 | 2293 | 2302 | 2311 |
| ·8 | 2320 | 2329 | 2338 | 2347 | 2356 | 2365 | 2374 | 2383 | 2392 | 2401 |
| ·9 | 2410 | 2419 | 2428 | 2437 | 2446 | 2455 | 2464 | 2473 | 2482 | 2491 |

TABLE 104 (*continued*).

| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 14·0 | 2500 | 2510 | 2520 | 2530 | 2540 | 2550 | 2560 | 2570 | 2580 | 2590 |
| ·1 | 2600 | 2610 | 2620 | 2630 | 2640 | 2650 | 2660 | 2670 | 2680 | 2690 |
| ·2 | 2700 | 2710 | 2720 | 2730 | 2740 | 2750 | 2760 | 2770 | 2780 | 2790 |
| ·3 | 2800 | 2810 | 2820 | 2830 | 2840 | 2850 | 2860 | 2870 | 2880 | 2890 |
| ·4 | 2900 | 2910 | 2920 | 2930 | 2940 | 2950 | 2960 | 2970 | 2980 | 2990 |
| ·5 | 3000 | 3012 | 3024 | 3036 | 3048 | 3060 | 3072 | 3084 | 3096 | 3108 |
| ·6 | 3120 | 3132 | 3144 | 3156 | 3168 | 3180 | 3192 | 3204 | 3216 | 3228 |
| ·7 | 3240 | 3252 | 3264 | 3276 | 3288 | 3300 | 3312 | 3324 | 3336 | 3348 |
| ·8 | 3360 | 3372 | 3384 | 3396 | 3408 | 3420 | 3432 | 3444 | 3456 | 3468 |
| ·9 | 3480 | 3492 | 3504 | 3516 | 3528 | 3540 | 3552 | 3564 | 3576 | 3588 |
| 15·0 | 3600 | 3612 | 3624 | 3636 | 3648 | 3660 | 3672 | 3684 | 3696 | 3708 |
| ·1 | 3720 | 3732 | 3744 | 3756 | 3768 | 3780 | 3792 | 3804 | 3816 | 3828 |
| ·2 | 3840 | 3852 | 3864 | 3876 | 3888 | 3900 | 3912 | 3924 | 3936 | 3948 |
| ·3 | 3960 | 3972 | 3984 | 3996 | 4008 | 4020 | 4032 | 4044 | 4056 | 4068 |
| ·4 | 4080 | 4092 | 4104 | 4116 | 4128 | 4140 | 4152 | 4164 | 4176 | 4188 |
| ·5 | 4200 | 4213 | 4226 | 4239 | 4252 | 4265 | 4278 | 4291 | 4304 | 4317 |
| ·6 | 4330 | 4343 | 4356 | 4369 | 4382 | 4395 | 4408 | 4421 | 4434 | 4447 |
| ·7 | 4460 | 4473 | 4486 | 4499 | 4512 | 4525 | 4538 | 4551 | 4564 | 4577 |
| ·8 | 4590 | 4604 | 4618 | 4632 | 4646 | 4660 | 4674 | 4688 | 4702 | 4716 |
| ·9 | 4730 | 4744 | 4758 | 4772 | 4786 | 4800 | 4814 | 4828 | 4842 | 4856 |
| 16·0 | 4870 | 4885 | 4900 | 4915 | 4930 | 4945 | 4960 | 4975 | 4990 | 5005 |
| ·1 | 5020 | 5035 | 5050 | 5065 | 5080 | 5095 | 5110 | 5125 | 5140 | 5155 |
| ·2 | 5170 | 5185 | 5200 | 5215 | 5230 | 5245 | 5260 | 5275 | 5290 | 5305 |
| ·3 | 5320 | 5336 | 5352 | 5368 | 5384 | 5400 | 5416 | 5432 | 5448 | 5464 |
| ·4 | 5480 | 5496 | 5512 | 5528 | 5544 | 5560 | 5576 | 5592 | 5608 | 5624 |
| ·5 | 5640 | 5656 | 5672 | 5688 | 5704 | 5720 | 5736 | 5752 | 5768 | 5784 |
| ·6 | 5800 | 5816 | 5832 | 5848 | 5864 | 5880 | 5896 | 5912 | 5928 | 5944 |
| ·7 | 5960 | 5977 | 5994 | 6011 | 6028 | 6045 | 6062 | 6079 | 6096 | 6113 |
| ·8 | 6130 | 6149 | 6168 | 6187 | 6206 | 6225 | 6244 | 6263 | 6282 | 6301 |
| ·9 | 6320 | 6339 | 6358 | 6377 | 6396 | 6415 | 6434 | 6453 | 6472 | 6491 |
| 17·0 | 6510 | 6529 | 6548 | 6567 | 6586 | 6605 | 6624 | 6643 | 6662 | 6681 |
| ·1 | 6700 | 6719 | 6738 | 6757 | 6776 | 6795 | 6814 | 6833 | 6852 | 6871 |
| ·2 | 6890 | 6910 | 6930 | 6950 | 6970 | 6990 | 7010 | 7030 | 7050 | 7070 |
| ·3 | 7090 | 7110 | 7130 | 7150 | 7170 | 7190 | 7210 | 7230 | 7250 | 7270 |
| ·4 | 7290 | 7310 | 7330 | 7350 | 7370 | 7390 | 7410 | 7430 | 7450 | 7470 |
| ·5 | 7490 | 7511 | 7532 | 7553 | 7574 | 7595 | 7616 | 7637 | 7658 | 7679 |
| ·6 | 7700 | 7722 | 7744 | 7766 | 7788 | 7810 | 7832 | 7854 | 7876 | 7898 |
| ·7 | 7920 | 7942 | 7964 | 7986 | 8008 | 8030 | 8052 | 8074 | 8096 | 8118 |
| ·8 | 8140 | 8162 | 8184 | 8206 | 8228 | 8250 | 8272 | 8294 | 8316 | 8338 |
| ·9 | 8360 | 8382 | 8404 | 8426 | 8448 | 8470 | 8492 | 8514 | 8536 | 8558 |
| 18·0 | 8580 | 8602 | 8624 | 8646 | 8668 | 8690 | 8712 | 8734 | 8756 | 8778 |
| ·1 | 8800 | 8823 | 8846 | 8869 | 8892 | 8915 | 8938 | 8961 | 8984 | 9907 |
| ·2 | 9030 | 9053 | 9076 | 9099 | 9122 | 9145 | 9168 | 9191 | 9214 | 9237 |

See note at bottom of Wadi Halfa Discharge Table (Table 107).

R.L. of zero, 373·41 metres.

TABLE 105.—DISCHARGE TABLE OF THE NILE AT TAMANIAT, 1912.

| Gauge-reading. | Discharge in cubic metres per second. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 9·5 | 400 | 405 | 410 | 415 | 420 | 425 | 430 | 435 | 440 | 445 |
| ·6 | 450 | 455 | 460 | 465 | 470 | 475 | 480 | 485 | 490 | 495 |
| ·7 | 500 | 505 | 510 | 515 | 520 | 525 | 530 | 535 | 540 | 545 |
| ·8 | 550 | 555 | 560 | 565 | 570 | 575 | 580 | 585 | 590 | 595 |
| ·9 | 600 | 605 | 610 | 615 | 620 | 625 | 630 | 635 | 640 | 645 |
| 10·0 | 650 | 655 | 660 | 665 | 670 | 675 | 680 | 685 | 690 | 695 |
| ·1 | 700 | 705 | 710 | 715 | 720 | 725 | 730 | 735 | 740 | 745 |
| ·2 | 750 | 755 | 760 | 765 | 770 | 775 | 780 | 785 | 790 | 795 |
| 3 | 800 | 805 | 810 | 815 | 820 | 825 | 830 | 835 | 840 | 845 |
| ·4 | 850 | 855 | 860 | 865 | 870 | 875 | 880 | 885 | 890 | 895 |
| 5 | 900 | 906 | 912 | 918 | 924 | 930 | 936 | 942 | 948 | 954 |
| ·6 | 960 | 966 | 972 | 978 | 984 | 990 | 996 | 1002 | 1008 | 1014 |
| ·7 | 1020 | 1026 | 1032 | 1038 | 1044 | 1050 | 1056 | 1062 | 1068 | 1074 |
| ·8 | 1080 | 1086 | 1092 | 1098 | 1104 | 1110 | 1116 | 1122 | 1128 | 1134 |
| ·9 | 1140 | 1146 | 1152 | 1158 | 1164 | 1170 | 1176 | 1182 | 1188 | 1194 |
| 11·0 | 1200 | 1207 | 1214 | 1221 | 1228 | 1235 | 1242 | 1249 | 1256 | 1263 |
| ·1 | 1270 | 1277 | 1284 | 1291 | 1298 | 1305 | 1312 | 1319 | 1326 | 1333 |
| ·2 | 1340 | 1347 | 1354 | 1361 | 1368 | 1375 | 1382 | 1389 | 1396 | 1403 |
| ·3 | 1410 | 1417 | 1424 | 1431 | 1438 | 1445 | 1452 | 1459 | 1466 | 1473 |
| ·4 | 1480 | 1487 | 1494 | 1501 | 1508 | 1515 | 1522 | 1529 | 1536 | 1543 |
| ·5 | 1550 | 1558 | 1566 | 1574 | 1582 | 1590 | 1598 | 1606 | 1614 | 1622 |
| ·6 | 1630 | 1638 | 1646 | 1654 | 1662 | 1670 | 1678 | 1686 | 1694 | 1702 |
| ·7 | 1710 | 1718 | 1726 | 1734 | 1742 | 1750 | 1758 | 1766 | 1774 | 1782 |
| ·8 | 1790 | 1798 | 1806 | 1814 | 1822 | 1830 | 1838 | 1846 | 1854 | 1862 |
| ·9 | 1870 | 1878 | 1886 | 1894 | 1902 | 1910 | 1918 | 1926 | 1934 | 1942 |
| 12·0 | 1950 | 1958 | 1966 | 1974 | 1982 | 1990 | 1998 | 2006 | 2014 | 2022 |
| ·1 | 2030 | 2038 | 2046 | 2054 | 2062 | 2070 | 2078 | 2086 | 2094 | 2102 |
| ·2 | 2110 | 2119 | 2128 | 2137 | 2146 | 2155 | 2164 | 2173 | 2182 | 2191 |
| ·3 | 2200 | 2209 | 2218 | 2227 | 2236 | 2245 | 2254 | 2263 | 2272 | 2281 |
| ·4 | 2290 | 2299 | 2308 | 2317 | 2326 | 2335 | 2344 | 2353 | 2362 | 2371 |
| ·5 | 2380 | 2390 | 2400 | 2410 | 2420 | 2430 | 2440 | 2450 | 2460 | 2470 |
| ·6 | 2480 | 2490 | 2500 | 2510 | 2520 | 2530 | 2540 | 2550 | 2560 | 2570 |
| ·7 | 2580 | 2590 | 2600 | 2610 | 2620 | 2630 | 2640 | 2650 | 2660 | 2670 |
| ·8 | 2680 | 2690 | 2700 | 2710 | 2720 | 2730 | 2740 | 2750 | 2760 | 2770 |
| ·9 | 2780 | 2790 | 2800 | 2810 | 2820 | 2830 | 2840 | 2850 | 2860 | 2870 |

TABLE 105 (*continued*).

| Gauge-reading. | Discharge in cubic metres per second. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 13·0 | 2880 | 2891 | 2902 | 2913 | 2924 | 2935 | 2946 | 2957 | 2968 | 2979 |
| ·1 | 2990 | 3001 | 3012 | 3023 | 3034 | 3045 | 3056 | 3067 | 3078 | 3089 |
| ·2 | 3100 | 3111 | 3122 | 3133 | 3144 | 3155 | 3166 | 3177 | 3188 | 3199 |
| ·3 | 3210 | 3222 | 3234 | 3246 | 3258 | 3270 | 3282 | 3294 | 3306 | 3318 |
| ·4 | 3330 | 3342 | 3354 | 3366 | 3378 | 3390 | 3402 | 3414 | 3426 | 3438 |
| ·5 | 3450 | 3463 | 3476 | 3489 | 3502 | 3515 | 3528 | 3541 | 3554 | 3567 |
| ·6 | 3580 | 3593 | 3606 | 3619 | 3632 | 3645 | 3658 | 3671 | 3684 | 3697 |
| ·7 | 3710 | 3723 | 3736 | 3749 | 3762 | 3775 | 3788 | 3801 | 3814 | 3827 |
| ·8 | 3840 | 3853 | 3866 | 3879 | 3892 | 3905 | 3918 | 3931 | 3944 | 3957 |
| ·9 | 3970 | 3983 | 3996 | 4009 | 4022 | 4035 | 4048 | 4061 | 4074 | 4087 |
| 14·0 | 4100 | 4115 | 4130 | 4145 | 4160 | 4175 | 4190 | 4205 | 4220 | 4235 |
| ·1 | 4250 | 4265 | 4280 | 4295 | 4310 | 4325 | 4340 | 4355 | 4370 | 4385 |
| ·2 | 4400 | 4415 | 4430 | 4445 | 4460 | 4475 | 4490 | 4505 | 4520 | 4535 |
| ·3 | 4550 | 4565 | 4580 | 4595 | 4610 | 4625 | 4640 | 4655 | 4670 | 4685 |
| ·4 | 4700 | 4715 | 4730 | 4745 | 4760 | 4775 | 4790 | 4805 | 4820 | 4835 |
| ·5 | 4850 | 4868 | 4886 | 4904 | 4922 | 4940 | 4958 | 4976 | 4994 | 5012 |
| ·6 | 5030 | 5048 | 5066 | 5084 | 5102 | 5120 | 5138 | 5156 | 5174 | 5192 |
| ·7 | 5210 | 5228 | 5246 | 5264 | 5282 | 5300 | 5318 | 5336 | 5354 | 5372 |
| ·8 | 5390 | 5408 | 5426 | 5444 | 5462 | 5480 | 5498 | 5516 | 5534 | 5552 |
| ·9 | 5570 | 5588 | 5606 | 5624 | 5642 | 5660 | 5678 | 5696 | 5714 | 5732 |
| 15·0 | 5750 | 5769 | 5788 | 5807 | 5826 | 5845 | 5864 | 5883 | 5902 | 5921 |
| ·1 | 5940 | 5959 | 5978 | 5997 | 6016 | 6035 | 6054 | 6073 | 6092 | 6111 |
| ·2 | 6130 | 6149 | 6168 | 6187 | 6206 | 6225 | 6244 | 6263 | 6282 | 6301 |
| ·3 | 6320 | 6339 | 6358 | 6377 | 6396 | 6415 | 6434 | 6453 | 6472 | 6491 |
| ·4 | 6510 | 6529 | 6548 | 6567 | 6586 | 6605 | 6624 | 6643 | 6662 | 6681 |
| ·5 | 6700 | 6721 | 6742 | 6763 | 6784 | 6805 | 6826 | 6847 | 6868 | 6889 |
| ·6 | 6910 | 6931 | 6952 | 6973 | 6994 | 7015 | 7036 | 7057 | 7078 | 7099 |
| ·7 | 7120 | 7141 | 7162 | 7183 | 7204 | 7225 | 7246 | 7267 | 7288 | 7309 |
| ·8 | 7330 | 7351 | 7372 | 7393 | 7414 | 7435 | 7456 | 7477 | 7498 | 7519 |
| ·9 | 7540 | 7561 | 7582 | 7603 | 7624 | 7645 | 7666 | 7687 | 7708 | 7729 |
| 16·0 | 7750 | 7777 | 7804 | 7831 | 7858 | 7885 | 7912 | 7939 | 7966 | 7993 |
| ·1 | 8020 | 8047 | 8074 | 8101 | 8128 | 8155 | 8182 | 8209 | 8236 | 8263 |
| ·2 | 8290 | 8317 | 8344 | 8371 | 8398 | 8425 | 8452 | 8479 | 8506 | 8533 |
| ·3 | 8560 | 8587 | 8614 | 8641 | 8668 | 8695 | 8722 | 8749 | 8776 | 8803 |
| ·4 | 8830 | 8857 | 8884 | 8911 | 8938 | 8965 | 8992 | 9019 | 9046 | 9073 |
| 16·5 | 9100 | 9127 | 9154 | 9181 | 9208 | 9235 | 9262 | 9289 | 9316 | 9343 |

R.L. zero of gauge, 360·13.

TABLE 106.—DISCHARGE TABLE OF THE ATBARA RIVER AT KHASHM EL GIRBA.
(Cubic metres per second).

| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0·0 | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 7 |
| ·1 | 8 | 8 | 9 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| ·2 | 16 | 16 | 17 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| ·3 | 24 | 24 | 25 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| ·4 | 32 | 32 | 33 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| ·5 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| ·6 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 |
| ·7 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
| ·8 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 |
| ·9 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 |
| 1·0 | 90 | 91 | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 |
| ·1 | 108 | 109 | 110 | 112 | 114 | 116 | 118 | 120 | 122 | 124 |
| ·2 | 126 | 127 | 128 | 130 | 132 | 134 | 136 | 138 | 140 | 142 |
| ·3 | 144 | 145 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 |
| ·4 | 162 | 163 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 |
| ·5 | 180 | 182 | 185 | 188 | 190 | 193 | 195 | 198 | 201 | 203 |
| ·6 | 206 | 208 | 211 | 214 | 216 | 219 | 221 | 224 | 227 | 229 |
| ·7 | 232 | 234 | 237 | 240 | 242 | 245 | 247 | 250 | 253 | 255 |
| ·8 | 258 | 260 | 263 | 266 | 268 | 271 | 273 | 276 | 279 | 281 |
| ·9 | 284 | 286 | 289 | 292 | 294 | 297 | 299 | 302 | 305 | 307 |
| 2·0 | 310 | 315 | 320 | 325 | 330 | 335 | 340 | 345 | 350 | 355 |
| ·1 | 360 | 365 | 370 | 375 | 380 | 385 | 390 | 395 | 400 | 405 |
| ·2 | 410 | 415 | 420 | 425 | 430 | 435 | 440 | 445 | 450 | 455 |
| ·3 | 460 | 465 | 470 | 475 | 480 | 485 | 490 | 495 | 500 | 505 |
| ·4 | 510 | 515 | 520 | 525 | 530 | 535 | 540 | 545 | 550 | 555 |
| ·5 | 560 | 565 | 571 | 576 | 582 | 588 | 593 | 599 | 605 | 610 |
| ·6 | 616 | 621 | 627 | 633 | 638 | 644 | 649 | 655 | 660 | 666 |
| 7 | 672 | 677 | 683 | 689 | 694 | 700 | 705 | 711 | 716 | 722 |
| ·8 | 728 | 733 | 739 | 745 | 750 | 756 | 761 | 767 | 773 | 778 |
| ·9 | 784 | 789 | 795 | 800 | 806 | 812 | 817 | 823 | 828 | 834 |
| 3·0 | 840 | 845 | 851 | 857 | 862 | 868 | 873 | 879 | 884 | 890 |
| ·1 | 896 | 901 | 907 | 912 | 918 | 924 | 929 | 935 | 940 | 946 |
| ·2 | 952 | 957 | 963 | 968 | 974 | 979 | 985 | 990 | 996 | 1002 |
| ·3 | 1008 | 1013 | 1019 | 1024 | 1030 | 1036 | 1041 | 1046 | 1052 | 1058 |
| ·4 | 1064 | 1069 | 1075 | 1080 | 1086 | 1091 | 1097 | 1102 | 1108 | 1114 |
| ·5 | 1120 | 1129 | 1139 | 1148 | 1158 | 1167 | 1177 | 1186 | 1196 | 1206 |
| ·6 | 1216 | 1225 | 1235 | 1244 | 1254 | 1263 | 1273 | 1282 | 1292 | 1302 |
| ·7 | 1312 | 1321 | 1331 | 1340 | 1350 | 1359 | 1368 | 1378 | 1388 | 1398 |
| ·8 | 1408 | 1417 | 1427 | 1436 | 1446 | 1455 | 1465 | 1474 | 1484 | 1494 |
| ·9 | 1504 | 1513 | 1523 | 1532 | 1542 | 1551 | 1561 | 1570 | 1580 | 1590 |

TABLE 106 (*continued*).

| Cent. / Met. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4·0 | 1600 | 1612 | 1624 | 1636 | 1648 | 1660 | 1672 | 1684 | 1696 | 1708 |
| ·1 | 1720 | 1732 | 1744 | 1756 | 1768 | 1780 | 1792 | 1804 | 1816 | 1828 |
| ·2 | 1840 | 1852 | 1864 | 1876 | 1888 | 1900 | 1912 | 1924 | 1936 | 1948 |
| ·3 | 1960 | 1972 | 1984 | 1996 | 2008 | 2020 | 2032 | 2044 | 2056 | 2068 |
| ·4 | 2080 | 2092 | 2104 | 2116 | 2128 | 2140 | 2152 | 2164 | 2176 | 2188 |
| ·5 | 2200 | 2214 | 2228 | 2242 | 2256 | 2270 | 2284 | 2298 | 2312 | 2326 |
| ·6 | 2340 | 2354 | 2368 | 2382 | 2396 | 2410 | 2424 | 2438 | 2452 | 2466 |
| ·7 | 2480 | 2494 | 2508 | 2522 | 2536 | 2550 | 2564 | 2578 | 2592 | 2606 |
| ·8 | 2620 | 2634 | 2648 | 2662 | 2676 | 2690 | 2704 | 2718 | 2732 | 2746 |
| ·9 | 2760 | 2774 | 2788 | 2802 | 2816 | 2830 | 2844 | 2858 | 2872 | 2886 |
| 5·0 | 2900 | 2917 | 2934 | 2951 | 2968 | 2985 | 3002 | 3019 | 3036 | 3053 |
| ·1 | 3070 | 3087 | 3104 | 3121 | 3138 | 3155 | 3172 | 3189 | 3206 | 3223 |
| ·2 | 3240 | 3257 | 3274 | 3291 | 3308 | 3325 | 3342 | 3359 | 3376 | 3393 |
| ·3 | 3410 | 3427 | 3444 | 3461 | 3478 | 3495 | 3512 | 3529 | 3546 | 3563 |
| ·4 | 3580 | 3597 | 3614 | 3631 | 3648 | 3665 | 3682 | 3699 | 3716 | 3733 |
| ·5 | 3750 | 3763 | 3776 | 3789 | 3802 | 3815 | 3828 | 3841 | 3854 | 3867 |
| ·6 | 3880 | 3893 | 3906 | 3919 | 3932 | 3945 | 3958 | 3971 | 3984 | 3997 |
| ·7 | 4010 | 4023 | 4036 | 4049 | 4062 | 4075 | 4088 | 4101 | 4114 | 4127 |
| ·8 | 4140 | 4153 | 4166 | 4179 | 4192 | 4205 | 4218 | 4231 | 4244 | 4257 |
| ·9 | 4270 | 4283 | 4296 | 4309 | 4322 | 4335 | 4348 | 4361 | 4374 | 4387 |
| 6·0 | 4400 | 4413 | 4426 | 4439 | 4452 | 4465 | 4478 | 4491 | 4504 | 4517 |
| ·1 | 4530 | | | | | | | | | |

For a rising river take the discharge for the gauge 10 centimetres higher; for a falling river take the discharge for the gauge 10 centimetres lower.

TABLE 107.—DISCHARGE TABLE OF THE NILE AT WADI HALFA.
(Calculated from Gauge Discharge Curves 1911–1912.)
(Above 7·50 from 1892.)

| Gauge-reading. | Discharge in cubic metres per second. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0·80 | 355 | 358 | 361 | 364 | 367 | 370 | 373 | 376 | 379 | 382 |
| 0·90 | 385 | 388 | 391 | 394 | 398 | 401 | 404 | 407 | 411 | 414 |
| 1·00 | 417 | 420 | 424 | 427 | 431 | 434 | 438 | 441 | 444 | 447 |
| ·10 | 450 | 454 | 459 | 463 | 467 | 471 | 476 | 480 | 484 | 488 |
| ·20 | 492 | 496 | 501 | 505 | 510 | 514 | 519 | 524 | 528 | 533 |
| ·30 | 538 | 542 | 546 | 550 | 555 | 560 | 565 | 570 | 575 | 580 |
| ·40 | 585 | 589 | 594 | 599 | 603 | 608 | 613 | 618 | 623 | 628 |
| ·50 | 633 | 639 | 645 | 650 | 655 | 660 | 665 | 670 | 675 | 680 |
| ·60 | 685 | 690 | 696 | 701 | 707 | 712 | 718 | 723 | 729 | 735 |
| ·70 | 740 | 745 | 750 | 756 | 762 | 768 | 774 | 780 | 786 | 792 |
| ·80 | 798 | 804 | 810 | 816 | 822 | 828 | 834 | 840 | 846 | 852 |
| ·90 | 858 | 864 | 870 | 876 | 882 | 888 | 894 | 900 | 906 | 912 |
| 2·00 | 918 | 925 | 932 | 939 | 945 | 951 | 957 | 963 | 969 | 975 |
| ·10 | 981 | 987 | 994 | 1,001 | 1,008 | 1,015 | 1,022 | 1,029 | 1,036 | 1,043 |
| ·20 | 1,050 | 1,057 | 1,064 | 1,071 | 1,078 | 1,085 | 1,092 | 1,099 | 1,106 | 1,113 |
| ·30 | 1,120 | 1,127 | 1,134 | 1,141 | 1,148 | 1,155 | 1,162 | 1,169 | 1,176 | 1,183 |
| ·40 | 1,190 | 1,198 | 1,206 | 1,214 | 1,222 | 1,230 | 1,237 | 1,244 | 1,251 | 1,258 |
| ·50 | 1,265 | 1,273 | 1,281 | 1,289 | 1,297 | 1,304 | 1,312 | 1,319 | 1,327 | 1,334 |
| ·60 | 1,340 | 1,347 | 1,355 | 1,362 | 1,370 | 1,377 | 1,385 | 1,392 | 1,400 | 1,407 |
| ·70 | 1,415 | 1,423 | 1,431 | 1,439 | 1,447 | 1,455 | 1,463 | 1,471 | 1,479 | 1,487 |
| ·80 | 1,495 | 1,503 | 1,512 | 1,520 | 1,529 | 1,537 | 1,546 | 1,554 | 1,563 | 1,571 |
| ·90 | 1,580 | 1,588 | 1,597 | 1,605 | 1,614 | 1,622 | 1,631 | 1,639 | 1,647 | 1,656 |
| 3·00 | 1,665 | 1,673 | 1,682 | 1,690 | 1,699 | 1,707 | 1,716 | 1,724 | 1,733 | 1,741 |
| ·10 | 1,750 | 1,759 | 1,768 | 1,777 | 1,786 | 1,795 | 1,804 | 1,813 | 1,822 | 1,831 |
| ·20 | 1,840 | 1,850 | 1,859 | 1,869 | 1,878 | 1,888 | 1,897 | 1,907 | 1,916 | 1,926 |
| ·30 | 1,935 | 1,945 | 1,955 | 1,965 | 1,975 | 1,985 | 1,995 | 2,005 | 2,015 | 2,025 |
| ·40 | 2,035 | 2,045 | 2,055 | 2,065 | 2,075 | 2,085 | 2,095 | 2,105 | 2,115 | 2,125 |
| ·50 | 2,135 | 2,145 | 2,156 | 2,166 | 2,177 | 2,187 | 2,198 | 2,208 | 2,219 | 2,229 |
| ·60 | 2,240 | 2,251 | 2,262 | 2,273 | 2,284 | 2,295 | 2,306 | 2,317 | 2,328 | 2,339 |
| ·70 | 2,350 | 2,362 | 2,374 | 2,386 | 2,398 | 2,410 | 2,422 | 2,434 | 2,446 | 2,458 |
| ·80 | 2,470 | 2,482 | 2,494 | 2,506 | 2,518 | 2,530 | 2,542 | 2,554 | 2,566 | 2,578 |
| ·90 | 2,590 | 2,602 | 2,614 | 2,626 | 2,638 | 2,650 | 2,662 | 2,674 | 2,686 | 2,698 |
| 4·00 | 2,710 | 2,722 | 2,734 | 2,746 | 2,758 | 2,770 | 2,782 | 2,794 | 2,806 | 2,818 |
| ·10 | 2,850 | 2,862 | 2,874 | 2,886 | 2,898 | 2,910 | 2,922 | 2,934 | 2,946 | 2,958 |
| ·20 | 2,970 | 2,982 | 2,994 | 3,006 | 3,018 | 3,030 | 3,042 | 3,054 | 3,066 | 3,078 |
| ·30 | 3,090 | 3,102 | 3,114 | 3,126 | 3,138 | 3,150 | 3,162 | 3,174 | 3,186 | 3,198 |
| ·40 | 3,210 | 3,222 | 3,234 | 3,246 | 3,258 | 3,270 | 3,282 | 3,294 | 3,306 | 3,318 |
| ·50 | 3,330 | 3,344 | 3,358 | 3,372 | 3,386 | 3,400 | 3,414 | 3,428 | 3,442 | 3,456 |
| ·60 | 3,470 | 3,484 | 3,498 | 3,512 | 3,526 | 3,540 | 3,554 | 3,568 | 3,582 | 3,596 |
| ·70 | 3,610 | 3,624 | 3,638 | 3,652 | 3,666 | 3,680 | 3,694 | 3,708 | 3,722 | 3,736 |
| ·80 | 3,750 | 3,765 | 3,780 | 3,795 | 3,810 | 3,825 | 3,840 | 3,855 | 3,870 | 3,885 |
| ·90 | 3,900 | 3,915 | 3,930 | 3,945 | 3,960 | 3,975 | 3,990 | 4,005 | 4,020 | 4,035 |

TABLE 107 (*continued*).

| Gauge-reading. Met. \ Cent. | Discharge in cubic metres per second. 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5·00 | 4,050 | 4,066 | 4,082 | 4,098 | 4,114 | 4,130 | 4,146 | 4,162 | 4,178 | 4,194 |
| ·10 | 4,210 | 4,226 | 4,242 | 4,258 | 4,274 | 4,290 | 4,306 | 4,322 | 4,338 | 4,354 |
| ·20 | 4,370 | 4,386 | 4,402 | 4,418 | 4,434 | 4,450 | 4,466 | 4,482 | 4,498 | 4,514 |
| ·30 | 4,530 | 4,546 | 4,562 | 4,578 | 4,594 | 4,610 | 4,626 | 4,642 | 4,658 | 4,674 |
| ·40 | 4,690 | 4,706 | 4,722 | 4,738 | 4,754 | 4,770 | 4,786 | 4,802 | 4,818 | 4,834 |
| ·50 | 4,850 | 4,867 | 4,884 | 4,901 | 4,918 | 4,935 | 4,952 | 4,969 | 4,988 | 5,003 |
| ·60 | 5,020 | 5,037 | 5,054 | 5,071 | 5,088 | 5,105 | 5,122 | 5,139 | 5,156 | 5,173 |
| ·70 | 5,190 | 5,207 | 5,224 | 5,241 | 5,258 | 5,275 | 5,292 | 5,309 | 5,326 | 5,343 |
| ·80 | 5,360 | 5,378 | 5,396 | 5,414 | 5,432 | 5,450 | 5,468 | 5,486 | 5,504 | 5,522 |
| ·90 | 5,540 | 5,558 | 5,576 | 5,594 | 5,612 | 5,630 | 5,648 | 5,666 | 5,684 | 5,702 |
| 6·00 | 5,720 | 5,740 | 5,750 | 5,770 | 5,790 | 5,810 | 5,820 | 5,840 | 5,860 | 5,870 |
| ·10 | 5,890 | 5,910 | 5,920 | 5,940 | 5,950 | 5,970 | 5,980 | 6,000 | 6,020 | 6,040 |
| ·20 | 6,060 | 6,080 | 6,090 | 6,110 | 6,120 | 6,140 | 6,150 | 6,170 | 6,190 | 6,210 |
| ·30 | 6,230 | 6,250 | 6,260 | 6,280 | 6,300 | 6,320 | 6,330 | 6,350 | 6,370 | 6,380 |
| ·40 | 6,400 | 6,420 | 6,430 | 6,450 | 6,470 | 6,490 | 6,500 | 6,520 | 6,540 | 6,550 |
| ·50 | 6,570 | 6,590 | 6,610 | 6,630 | 6,650 | 6,670 | 6,680 | 6,700 | 6,720 | 6,740 |
| ·60 | 6,760 | 6,780 | 6,800 | 6,820 | 6,840 | 6,860 | 6,870 | 6,890 | 6,910 | 6,930 |
| ·70 | 6,950 | 6,970 | 6,990 | 7,010 | 7,030 | 7,050 | 7,060 | 7,080 | 7,100 | 7,120 |
| ·80 | 7,140 | 7,160 | 7,180 | 7,200 | 7,220 | 7,240 | 7,250 | 7,270 | 7,290 | 7,310 |
| ·90 | 7,330 | 7,350 | 7,370 | 7,390 | 7,410 | 7,430 | 7,440 | 7,460 | 7,480 | 7,500 |
| 7·00 | 7,520 | 7,540 | 7,560 | 7,580 | 7,600 | 7,620 | 7,630 | 7,650 | 7,670 | 7,690 |
| ·10 | 7,710 | 7,730 | 7,750 | 7,770 | 7,790 | 7,810 | 7,830 | 7,850 | 7,870 | 7,890 |
| ·20 | 7,910 | 7,930 | 7,950 | 7,970 | 7,990 | 8,010 | 8,030 | 8,050 | 8,070 | 8,090 |
| ·30 | 8,110 | 8,130 | 8,150 | 8,170 | 8,190 | 8,210 | 8,230 | 8,250 | 8,270 | 8,290 |
| ·40 | 8,310 | 8,330 | 8,350 | 8,370 | 8,390 | 8,410 | 8,430 | 8,450 | 8,470 | 8,490 |
| ·50 | 8,510 | 8,530 | 8,550 | 8,570 | 8,590 | 8,620 | 8,640 | 8,660 | 8,680 | 8,700 |
| ·60 | 8,720 | 8,740 | 8,760 | 8,780 | 8,800 | 8,830 | 8,850 | 8,870 | 8,890 | 8,910 |
| ·70 | 8,930 | 8,950 | 8,970 | 8,990 | 9,010 | 9,040 | 9,060 | 9,080 | 9,100 | 9,120 |
| ·80 | 9,140 | 9,160 | 9,180 | 9,210 | 9,230 | 9,250 | 9,270 | 9,290 | 9,320 | 9,340 |
| ·90 | 9,360 | 9,380 | 9,400 | 9,430 | 9,450 | 9,470 | 9,490 | 9,510 | 9,540 | 9,560 |
| 8·00 | 9,580 | 9,600 | 9,620 | 9,650 | 9,670 | 9,690 | 9,710 | 9,730 | 9,760 | 9,780 |
| ·10 | 9,810 | 9,830 | 9,860 | 9,880 | 9,900 | 9,930 | 9,950 | 9,970 | 9,990 | 10,020 |
| ·20 | 10,040 | 10,060 | 10,090 | 10,110 | 10,130 | 10,160 | 10,180 | 10,200 | 10,220 | 10,250 |
| ·30 | 10,270 | 10,290 | 10,320 | 10,340 | 10,360 | 10,390 | 10,410 | 10,440 | 10,460 | 10,480 |
| ·40 | 10·500 | 10,520 | 10,550 | 10,570 | 10,600 | 10,620 | 10,650 | 10,670 | 10,700 | 10,720 |
| ·50 | 10,740 | 10,760 | 10,790 | 10,820 | 10,840 | 10,870 | 10,900 | 10,920 | 10.950 | 10,970 |
| ·60 | 10,990 | 11,010 | 11,040 | 11,060 | 11,090 | 11,110 | 11,140 | 11,160 | 11,190 | 11,210 |
| ·70 | 11,240 | 11,260 | 11,290 | 11,310 | 11,340 | 11,360 | 11,390 | 11,410 | 11,440 | 11,460 |
| ·80 | 11,490 | 11,510 | 11,540 | 11,560 | 11,590 | 11,610 | 11,640 | 11,660 | 11,690 | 11,710 |
| ·90 | 11,740 | 11,760 | 11,790 | 11,820 | 11,850 | 11,870 | 11,900 | 11,920 | 11,950 | 11,970 |
| 9·00 | 12,000 | | | | | | | | | |

Below 3·00 metres take the discharge opposite the gauge. Above 3·00 metres for a rising Nile take the discharge 10 centimetres higher than the gauge, and for a falling Nile 10 centimetres lower. R.L. of zero, 116·70 metres.

Between ·50$^{m}$ and ·80$^{m}$ on the gauge, the discharges are roughly as follows:—

| Gauge. | Discharge. | Gauge. | Discharge. |
|---|---|---|---|
| ·50 | 275 cubic metres per second. | ·70 | 325 cubic metres per second. |
| 60 | 300 ,, ,, | ·80 | 355 ,, ,, |

TABLE 108.—DISCHARGE TABLE OF THE NILE AT ASWAN.
(In reduced levels.)

| Gauge-reading. Met. \ Cent. | Discharge in cubic metres per second. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 84·0 | 350 | 353 | 356 | 359 | 362 | 365 | 368 | 371 | 374 | 377 |
| ·1 | 380 | 383 | 386 | 389 | 392 | 395 | 398 | 401 | 404 | 407 |
| ·2 | 410 | 413 | 416 | 419 | 422 | 425 | 428 | 431 | 434 | 437 |
| ·3 | 440 | 443 | 446 | 449 | 452 | 455 | 458 | 461 | 464 | 467 |
| ·4 | 470 | 473 | 476 | 479 | 482 | 485 | 488 | 491 | 494 | 497 |
| ·5 | 500 | 504 | 508 | 512 | 516 | 520 | 524 | 528 | 532 | 536 |
| ·6 | 540 | 544 | 548 | 552 | 556 | 560 | 564 | 568 | 572 | 576 |
| ·7 | 580 | 584 | 588 | 592 | 596 | 600 | 604 | 608 | 612 | 616 |
| ·8 | 620 | 624 | 628 | 632 | 636 | 640 | 644 | 648 | 652 | 656 |
| ·9 | 660 | 664 | 668 | 672 | 676 | 680 | 684 | 688 | 692 | 696 |
| 85·0 | 700 | 704 | 708 | 712 | 716 | 720 | 724 | 728 | 732 | 736 |
| ·1 | 740 | 744 | 748 | 752 | 756 | 760 | 764 | 768 | 772 | 776 |
| ·2 | 780 | 785 | 790 | 795 | 800 | 805 | 810 | 815 | 820 | 825 |
| ·3 | 830 | 835 | 840 | 845 | 850 | 855 | 860 | 865 | 870 | 875 |
| ·4 | 880 | 885 | 890 | 895 | 900 | 905 | 910 | 915 | 920 | 925 |
| ·5 | 930 | 935 | 940 | 945 | 950 | 955 | 960 | 965 | 970 | 975 |
| ·6 | 980 | 985 | 990 | 995 | 1,000 | 1,005 | 1,010 | 1,015 | 1,020 | 1,025 |
| ·7 | 1,030 | 1,035 | 1,040 | 1,045 | 1,050 | 1,055 | 1,060 | 1,065 | 1,070 | 1,075 |
| ·8 | 1,080 | 1,086 | 1,092 | 1,098 | 1,104 | 1,110 | 1,116 | 1,122 | 1,128 | 1,134 |
| ·9 | 1,140 | 1,146 | 1,152 | 1,158 | 1,164 | 1,170 | 1,176 | 1,182 | 1,188 | 1,194 |
| 86·0 | 1,200 | 1,206 | 1,212 | 1,218 | 1,224 | 1,230 | 1,236 | 1,242 | 1,248 | 1,254 |
| ·1 | 1,260 | 1,266 | 1,272 | 1,278 | 1,284 | 1,290 | 1,296 | 1,302 | 1,308 | 1,314 |
| ·2 | 1,320 | 1,326 | 1,332 | 1,338 | 1,344 | 1,350 | 1,356 | 1,362 | 1,368 | 1,374 |
| ·3 | 1,380 | 1,387 | 1,394 | 1,401 | 1,408 | 1,415 | 1,422 | 1,429 | 1,436 | 1,443 |
| ·4 | 1,450 | 1,457 | 1,464 | 1,471 | 1,478 | 1,485 | 1,492 | 1,499 | 1,506 | 1,513 |
| ·5 | 1,520 | 1,527 | 1,534 | 1,541 | 1,548 | 1,555 | 1,562 | 1,569 | 1,576 | 1,583 |
| ·6 | 1,590 | 1,597 | 1,604 | 1,611 | 1,618 | 1,625 | 1,632 | 1,639 | 1,646 | 1,653 |
| ·7 | 1,660 | 1,668 | 1,676 | 1,684 | 1,692 | 1,700 | 1,708 | 1,716 | 1,724 | 1,732 |
| ·8 | 1,740 | 1,748 | 1,756 | 1,764 | 1,772 | 1,780 | 1,788 | 1,796 | 1,804 | 1,812 |
| ·9 | 1,820 | 1,828 | 1,836 | 1,844 | 1,852 | 1,860 | 1,868 | 1,876 | 1,884 | 1,892 |
| 87·0 | 1,900 | 1,908 | 1,916 | 1,924 | 1,932 | 1,940 | 1,948 | 1,956 | 1,964 | 1,972 |
| ·1 | 1,980 | 1,988 | 1,996 | 2,004 | 2,012 | 2,020 | 2,028 | 2,036 | 2,044 | 2,052 |
| ·2 | 2,060 | 2,068 | 2,076 | 2,084 | 2,092 | 2,100 | 2,108 | 2,116 | 2,124 | 2,132 |
| ·3 | 2,140 | 2,149 | 2,158 | 2,167 | 2,176 | 2,185 | 2,194 | 2,203 | 2,212 | 2,221 |
| ·4 | 2,230 | 2,239 | 2,248 | 2,257 | 2,266 | 2,275 | 2,284 | 2,293 | 2,302 | 2,311 |
| ·5 | 2,320 | 2,329 | 2,338 | 2,347 | 2,356 | 2,365 | 2,374 | 2,383 | 2,392 | 2,401 |
| ·6 | 2,410 | 2,419 | 2,428 | 2,437 | 2,446 | 2,455 | 2,464 | 2,473 | 2,482 | 2,491 |
| ·7 | 2,500 | 2,509 | 2,518 | 2,527 | 2,536 | 2,545 | 2,554 | 2,563 | 2,572 | 2,581 |
| ·8 | 2,590 | 2,599 | 2,608 | 2,617 | 2,626 | 2,635 | 2,644 | 2,653 | 2,662 | 2,671 |
| ·9 | 2,680 | 2,690 | 2,700 | 2,710 | 2,720 | 2,730 | 2,740 | 2,750 | 2,760 | 2,770 |

TABLE 108 (*continued*).

| Gauge-reading. Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Discharge in cubic metres per second. | | | | | | | | | |
| 88·0 | 2,780 | 2,790 | 2,800 | 2,810 | 2,820 | 2,830 | 2,840 | 2,850 | 2,860 | 2,870 |
| ·1 | 2,880 | 2,890 | 2,900 | 2,910 | 2,920 | 2,930 | 2,940 | 2,950 | 2,960 | 2,970 |
| ·2 | 2,980 | 2,990 | 3,000 | 3,010 | 3,020 | 3,030 | 3,040 | 3,050 | 3,060 | 3,070 |
| ·3 | 3,080 | 3,090 | 3,100 | 3,110 | 3,120 | 3,130 | 3,140 | 3,150 | 3,160 | 3,170 |
| ·4 | 3,180 | 3,190 | 3,200 | 3,210 | 3,220 | 3,230 | 3,240 | 3,250 | 3,260 | 3,270 |
| ·5 | 3,280 | 3,290 | 3,300 | 3,310 | 3,320 | 3,330 | 3,340 | 3,350 | 3,360 | 3,370 |
| ·6 | 3,380 | 3,390 | 3,400 | 3,410 | 3,420 | 3,430 | 3,440 | 3,450 | 3,460 | 3,470 |
| ·7 | 3,480 | 3,490 | 3,500 | 3,510 | 3,520 | 3,530 | 3,540 | 3,550 | 3,560 | 3,570 |
| ·8 | 3,580 | 3,591 | 3,602 | 3,613 | 3,624 | 3,635 | 3,646 | 3,657 | 3,668 | 3,679 |
| ·9 | 3,690 | 3,701 | 3,712 | 3,723 | 3,734 | 3,745 | 3,756 | 3,767 | 3,778 | 3,789 |
| 89·0 | 3,800 | 3,811 | 3,822 | 3,833 | 3,844 | 3,855 | 3,866 | 3,877 | 3,888 | 3,899 |
| ·1 | 3,910 | 3,921 | 3,932 | 3,943 | 3,954 | 3,965 | 3,976 | 3,987 | 3,998 | 4,009 |
| ·2 | 4,020 | 4,031 | 4,042 | 4,053 | 4,064 | 4,075 | 4,086 | 4,097 | 4,108 | 4,119 |
| ·3 | 4,130 | 4,141 | 4,152 | 4,163 | 4,174 | 4,185 | 4,196 | 4,207 | 4,218 | 4,229 |
| ·4 | 4,240 | 4,252 | 4,264 | 4,276 | 4,288 | 4,300 | 4,312 | 4,324 | 4,336 | 4,348 |
| ·5 | 4,360 | 4,372 | 4,384 | 4,396 | 4,408 | 4,420 | 4,432 | 4,444 | 4,456 | 4,468 |
| ·6 | 4,480 | 4,493 | 4,506 | 4,519 | 4,532 | 4,545 | 4,558 | 4,571 | 4,584 | 4,597 |
| ·7 | 4,610 | 4,623 | 4,636 | 4,649 | 4,662 | 4,675 | 4,688 | 4,701 | 4,714 | 4,727 |
| ·8 | 4,740 | 4,753 | 4,766 | 4,779 | 4,792 | 4,805 | 4,818 | 4,831 | 4,844 | 4,857 |
| ·9 | 4,870 | 4,883 | 4,896 | 4,909 | 4,922 | 4,935 | 4,948 | 4,961 | 4,974 | 4,987 |
| 90·0 | 5,000 | 5,013 | 5,026 | 5,039 | 5,052 | 5,065 | 5,078 | 5,091 | 5,104 | 5,117 |
| ·1 | 5,130 | 5,143 | 5,156 | 5,169 | 5,182 | 5,195 | 5,208 | 5,221 | 5,234 | 5,247 |
| ·2 | 5,260 | 5,274 | 5,288 | 5,302 | 5,316 | 5,330 | 5,344 | 5,358 | 5,372 | 5,386 |
| ·3 | 5,400 | 5,414 | 5,428 | 5,442 | 5,456 | 5,470 | 5,484 | 5,498 | 5,512 | 5,526 |
| ·4 | 5,540 | 5,554 | 5,568 | 5,582 | 5,596 | 5,610 | 5,624 | 5,638 | 5,652 | 5,666 |
| ·5 | 5,680 | 5,694 | 5,708 | 5,722 | 5,736 | 5,750 | 5,764 | 5,778 | 5,792 | 5,806 |
| ·6 | 5,820 | 5,834 | 5,848 | 5,862 | 5,876 | 5,890 | 5,904 | 5,918 | 5,932 | 5,946 |
| ·7 | 5,960 | 5,974 | 5,988 | 6,002 | 6,016 | 6,030 | 6,044 | 6,058 | 6,072 | 6,086 |
| ·8 | 6,100 | 6,115 | 6,130 | 6.145 | 6,160 | 6,175 | 6,190 | 6,205 | 6,220 | 6,235 |
| ·9 | 6,250 | 6,265 | 6,280 | 6,295 | 6,310 | 6,325 | 6,340 | 6,355 | 6,370 | 6,385 |
| 91·0 | 6,400 | 6,416 | 6,432 | 6,448 | 6,464 | 6,480 | 6,496 | 6,512 | 6,528 | 6,544 |
| ·1 | 6,560 | 6,576 | 6,592 | 6,608 | 6,624 | 6,640 | 6,656 | 6,672 | 6,688 | 6,704 |
| ·2 | 6,720 | 6,736 | 6,752 | 6,768 | 6,784 | 6,800 | 6,816 | 6,832 | 6,848 | 6,864 |
| ·3 | 6,880 | 6,896 | 6,912 | 6,928 | 6,944 | 6,960 | 6,976 | 6,992 | 7,008 | 7,024 |
| ·4 | 7,040 | 7,056 | 7,072 | 7,088 | 7,104 | 7,120 | 7,136 | 7,152 | 7,168 | 7,184 |
| ·5 | 7,200 | 7,218 | 7,236 | 7,254 | 7,272 | 7,290 | 7,308 | 7,326 | 7,344 | 7,362 |
| ·6 | 7,380 | 7,398 | 7,416 | 7,434 | 7,452 | 7,470 | 7,488 | 7,506 | 7,524 | 7,542 |
| ·7 | 7,560 | 7,578 | 7,596 | 7,614 | 7,632 | 7,650 | 7,668 | 7,686 | 7,704 | 7,722 |
| ·8 | 7,740 | 7,758 | 7,776 | 7,794 | 7,812 | 7,830 | 7,848 | 7,866 | 7,884 | 7,902 |
| ·9 | 7,920 | 7,938 | 7,956 | 7,974 | 7,992 | 8,010 | 8,028 | 8,046 | 8,064 | 8,082 |

TABLE 108.—DISCHARGE TABLE OF THE NILE AT ASWAN (*continued*).

| Gauge-reading. Met. \ Cent. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Discharge in cubic metres per second. | | | | | | | | | |
| 92·0 | 8,100 | 8,120 | 8,140 | 8,160 | 8,180 | 8,200 | 8,220 | 8,240 | 8,260 | 8,280 |
| ·1 | 8,300 | 8,320 | 8,340 | 8,360 | 8,380 | 8,400 | 8,420 | 8,440 | 8,460 | 8,480 |
| ·2 | 8,500 | 8,520 | 8,540 | 8,560 | 8,580 | 8,600 | 8,620 | 8,640 | 8,660 | 8,680 |
| ·3 | 8,700 | 8,720 | 8,740 | 8,760 | 8,780 | 8,800 | 8,820 | 8,840 | 8,860 | 8,880 |
| ·4 | 8,900 | 8,920 | 8,940 | 8,960 | 8,980 | 9,000 | 9,020 | 9,040 | 9,060 | 9,080 |
| ·5 | 9,100 | 9,122 | 9,144 | 9,166 | 9,188 | 9,210 | 9,232 | 9,254 | 9,276 | 9,298 |
| ·6 | 9,320 | 9,342 | 9,364 | 9,386 | 9,408 | 9,430 | 9,452 | 9,474 | 9,496 | 9,518 |
| ·7 | 9,540 | 9,562 | 9,584 | 9,606 | 9,628 | 9,650 | 9,672 | 9,694 | 9,716 | 9,738 |
| ·8 | 9,760 | 9,782 | 9,804 | 9,826 | 9,848 | 9,870 | 9,892 | 9,914 | 9,936 | 9,958 |
| ·9 | 9,980 | 10,002 | 10,024 | 10,046 | 10,068 | 10,090 | 10,112 | 10,134 | 10,156 | 10,178 |
| 93·0 | 10,200 | 10,224 | 10,248 | 10,272 | 10,296 | 10,320 | 10,344 | 10,368 | 10,392 | 10,416 |
| ·1 | 10,440 | 10,464 | 10,488 | 10,512 | 10,536 | 10,560 | 10,584 | 10,608 | 10,632 | 10,656 |
| ·2 | 10,680 | 10,704 | 10,728 | 10,752 | 10,776 | 10,800 | 10,824 | 10,848 | 10,872 | 10,896 |
| ·3 | 10,920 | 10,944 | 10,968 | 10,992 | 11,016 | 11,040 | 11,064 | 11,088 | 11,112 | 11,136 |
| ·4 | 11,160 | 11,184 | 11,208 | 11,232 | 11,256 | 11,280 | 11,304 | 11,328 | 11,352 | 11,376 |
| ·5 | 11,400 | 11,428 | 11,456 | 11,484 | 11,512 | 11,540 | 11,568 | 11,596 | 11,624 | 11,652 |
| ·6 | 11,680 | 11,708 | 11,736 | 11,764 | 11,792 | 11,820 | 11,848 | 11,876 | 11,904 | 11,932 |
| ·7 | 11,960 | 11,988 | 12,016 | 12,044 | 12,072 | 12,100 | 12,128 | 12,156 | 12,184 | 12,212 |
| ·8 | 12,240 | 12,268 | 12,296 | 12,324 | 12,352 | 12,380 | 12,408 | 12,436 | 12,464 | 12,492 |
| ·9 | 12,520 | 12,548 | 12,576 | 12,604 | 12,632 | 12,660 | 12,688 | 12,716 | 12,744 | 12,772 |
| 94·0 | 12,800 | 12,830 | 12,860 | 12,890 | 12,920 | 12,950 | 12,980 | 13,010 | 13,040 | 13,070 |
| ·1 | 13,100 | 13,130 | 13,160 | 13,190 | 13,220 | 13,250 | 13,280 | 13,310 | 13,340 | 13,370 |
| ·2 | 13,400 | 13,430 | 13,460 | 13,490 | 13,520 | 13,550 | 13,580 | 13,610 | 13,640 | 13,670 |

This gauge is very unreliable for discharges below 86·00. Variations have been as follows:—1903 – ·20; 1904-5 – ·10; 1906-7-8-9 as in table; 1910 – ·20; 1911 – ·40. Thus in 1911 a gauge of 85·10 gave a discharge corresponding to 85·10 – ·40, or 84·70, *i.e.* 580 instead of 740 cubic metres per second. For low readings the gauge might go to Silsila or elsewhere.

TABLE 109.—MEASURED WINTER AND SUMMER DISCHARGES OF THE ALBERT NILE JUST ABOVE LAKE NO.

(In cubic metres per second.)

| Mongalla Discharge. | Date. | Discharge of the Albert Nile into Lake No. |
|---|---|---|
| 550 | April 14, 1900 . | 220. Very low year at Mongalla. |
| 690 | " 14, 1903 . | 290 |
| 1130 | May 22, 1904 . | 320 |
| 1100 | February 28, 1906 . | 330 Very high year " |
| 1100 | May 31, 1906 . | 340 |
| 600 | March 12, 1911 . | 350 |
| 550 | February 4, 1912 . | 360. Very low year " |

TABLE 110.—DINDER RIVER DISCHARGE TABLE, 1911, FOR ABU HASHIM GAUGE.
(Cubic metres per second.)

| Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
|---|---|---|---|---|---|
| 10·5 | 10·0 | 13·0 | 150·0 | 15·5 | 480·0 |
| ·6 | 12·0 | ·1 | 160·0 | ·6 | 497·0 |
| ·7 | 14·0 | ·2 | 170·0 | ·7 | 514·0 |
| ·8 | 16·0 | ·3 | 180·0 | ·8 | 531·0 |
| ·9 | 19·0 | ·4 | 190·0 | ·9 | 548·0 |
| 11·0 | 22·0 | ·5 | 200·0 | 16·0 | 565·0 |
| ·1 | 26·0 | ·6 | 212·0 | ·1 | 583·0 |
| ·2 | 30·0 | ·7 | 224·0 | ·2 | 601·0 |
| ·3 | 35·0 | ·8 | 236·0 | ·3 | 619·0 |
| ·4 | 40·0 | ·9 | 250·0 | ·4 | 637·0 |
| ·5 | 46·0 | 14·0 | 265·0 | ·5 | 655·0 |
| ·6 | 52·0 | ·1 | 278·0 | ·6 | 673·0 |
| ·7 | 58·0 | ·2 | 291·0 | ·7 | 691·0 |
| ·8 | 64·0 | ·3 | 304·0 | ·8 | 709·0 |
| ·9 | 72·0 | ·4 | 317·0 | ·9 | 727·0 |
| 12·0 | 80·0 | ·5 | 330·0 | 17·0 | 745·0 |
| ·1 | 87·0 | ·6 | 344·0 | ·1 | 765·0 |
| ·2 | 94·0 | ·7 | 358·0 | ·2 | 758·0 |
| ·3 | 101·0 | ·8 | 372·0 | ·3 | 805·0 |
| ·4 | 108·0 | ·9 | 386·0 | ·4 | 825·0 |
| ·5 | 115·0 | 15·0 | 400·0 | ·5 | 845·0 |
| ·6 | 122·0 | ·1 | 415·0 | ·6 | 865·0 |
| ·7 | 129·0 | ·2 | 430·0 | ·7 | 885·0 |
| ·8 | 136·0 | ·3 | 446·0 | ·8 | 1005·0 |
| ·9 | 143·0 | ·4 | 463·0 | ·9 | 1025·0 |

R.L. zero of gauge, 409·09.

TABLE III.—LIST OF DISCHARGE OBSERVATIONS ON THE ALBERT NILE BETWEEN GONDOKORO AND LAKE NO FROM 1906 UP TO MAY 1912.
(Cubic metres per second.)

| Date. | Site. | Gauge. Name. | Gauge. Reading. | Discharge. | Mongalla Discharge. |
|---|---|---|---|---|---|
| 1906 | | | | | |
| Jan. 30 | Just above Lake No | ... | ... | 332 | 1190 |
| Feb. 5 | ,, ,, | ... | ... | 320 | 970 |
| Mar. 17 | Mongalla | ... | ... | 932 | |
| 18 | Aliab | ... | ... | 120 | |
| 19 | Bor | ... | ... | 721 | 940 |
| 24 | U.S. Awai inlets | ... | ... | 199 | |
| 24 | Awai inlets | ... | ... | 192 | |
| 24 | U.S. Awai inlets | ... | ... | 199 | |
| 24 | D.S. Awai inlets | ... | ... | 391 | |
| 25 | D.S. No. 15 false channel | ... | ... | 249 | |
| 26 | U.S. ,, ,, | ... | ... | 386 | |
| June 26 | False channel | ... | ... | 121 | |
| Mar. 27 | U.S. Hillet Nuer gauge | ... | ... | 441 | 1080 |
| 27 | D.S. ,, 208 kilometres U.S. Lake No | ... | ... | 420 | 1080 |
| 27 | 187 kilometres U.S. of Lake No | ... | ... | 406 | 1080 |
| 28 | 156 ,, ,, ,, | ... | ... | 427 | 1080 |
| 28 | 126 ,, ,, ,, | ... | ... | 375 | 1080 |
| 28 | 98 ,, ,, ,, | ... | ... | 349 | 1080 |
| 29 | 87 ,, ,, ,, | ... | ... | 365 | 1100 |
| 29 | 66·5 ,, ,, ,, | ... | ... | 344 | 1100 |
| 29 | 48 ,, ,, ,, | ... | ... | 341 | 1100 |
| 29 | 48 ,, ,, ,, | ... | ... | 347 | 1100 |
| 31 | 36 ,, ,, ,, | ... | ... | 340 | 1100 |
| 31 | 24 ,, ,, ,, | ... | ... | 331 | 1100 |
| 31 | 11 ,, ,, ,, | ... | ... | 333 | 1100 |
| May 29 | 36 ,, ,, ,, | ... | ... | 334 | 1110 |
| 31 | 11 ,, ,, ,, | ... | ... | 327 | 1110 |
| Mar. 31 | Just above Lake No | ... | ... | 329 | 1100 |
| May 31 | ,, ,, | ... | ... | 344 | 1110 |
| 1907 | | | | | |
| Dec. 22 | Mongalla | Mongalla | 11·92 | 1043 | |
| 1908 | | | | | |
| Apr. 2 | Bor | Bor | 11·07 | 624 | 710 |
| 4 | Mongalla | Mongalla | 11·22 | 791 | |
| May 7 | ,, | ,, | 11·40 | 808 | |
| 7 | ,, | ,, | 11·40 | 814 | |
| 8 | Eastern branch Gimeza wood sta. | Bor | 11·14 | 602 | |
| 9 | Western ,, 2 kilometres U.S. cross cut | ,, | 11·14 | 233 | |

TABLE III (*continued*).

| Date. | Site. | Gauge. Name. | Gauge. Reading. | Discharge. | Mongalla Discharge. |
|---|---|---|---|---|---|
| 1908 | | | | | |
| May 9 | Aliab 500 metres below point where it leaves the west channel . . | Bor | 11·14 | 23 | |
| 9 | Bor . . . . . . . | ” | 11·14 | 651 | 760 |
| July 10 | ” . . . . . . . | ” | 11·30 | 781 | 970 |
| 11 | Mongalla . . . . . | Mongalla | 11·98 | 1045 | |
| 13 | Bor . . . . . . . | Bor | 11·32 | 729 | 1000 |
| 17 | Buffalo Cape . . . . . | Buf. Cape | 11·50 | 382 | 970 |
| Dec. 7 | Bor in front of Telegraph House . | Bor | 11·49 | 713 | 890 |
| 13 | Mongalla . . . . . | Mongalla | 11·72 | 868 | |
| 1909 | | | | | |
| Mar. 28 | Bor . . . . . . . | Bor | 11·03 | 633 | 770 |
| 29 | Mongalla . . . . . | Mongalla | 11·34 | 778 | |
| May 21 | Bor . . . . . . . | Bor | 11·35 | 791 | |
| 23 | Mongalla . . . . . | Mongalla | 11·74 | 954 | |
| 1910 | | | | | |
| Nov. 28 | Ghaba el Inderab . . . . . | Gh. Ind. | 11·52 | 379 | |
| Dec. 16 | Just above new cut . . . | Head of cut | 11·47 | 348 | |
| 30 | Ghaba el Inderab . . . . . | Gh. Ind. | 11·48 | 365 | |
| 31 | Near K.P. 320* . . . . . | ... | ... | 613 | |
| 31 | ” 340 . . . . . | ... | ... | 465 | |
| 31 | ” 360 . . . . . | ... | ... | 589 | |
| 1911 | | | | | |
| Jan. 1 | Near K.P. 380 . . . . . | ... | ... | 403 | |
| 1 | ” 405 . . . . . | ... | ... | 467 | |
| 2 | ” 440 . . . . . | ... | ... | 238 | |
| 3 | ” 480 . . . . . | ... | ... | 361 | |
| 4 | ” 520 . . . . . | ... | ... | 378 | |
| 5 | ” 560 . . . . . | ... | ... | 399 | |
| 7 | ” 600 . . . . . | ... | ... | 654 | |
| 8 | Bor . . . . . . . | Bor | 11·01 | 730 | |
| 8 | Bor south 500 metres D.S. of junction of east and west channels . . | ... | ... | 745 | |
| 9 | West channel south of Bor 1/K.D.S. of junction of cross channel . | ... | ... | 474 | |
| 9 | 5 kilometres of Bor cross channel just above its junction with west channel . . . . . . | ... | ... | 241 | |
| 9 | South of Bor Sheikh Tombe west channel . . . . . . | ... | ... | 217 | |
| 10 | West channel 100 metres D.S. of point where east channel takes off . . . . . . . | ... | ... | 260 | |

* K.P. is kilo pole placed on edge of the Albert Nile and measured up from Lake No.

TABLE 111.—LIST OF DISCHARGE OBSERVATIONS (*continued*).

| Date. | | Site. | Gauge. Name. | Gauge. Reading. | Discharge. | Mongalla Discharge. |
|---|---|---|---|---|---|---|
| 1911 | | | | | | |
| Jan. | 10 | South of Bor 200 metres U.S. of south junction of east and west channels | ... | ... | 785 | |
| | 11 | 1½ kilometres D.S. of Mongalla | Mongalla | 11·30 | 809 | |
| | 13 | South of Bor east channel, 1 kilometre U.S. of its northern junction with Albert Nile | ... | ... | 245 | |
| | 13 | South of Bor cross channel junction with east channel | ... | ... | 266 | |
| | 14 | South of Bor ½ kilometre D.S. of bifurcation of the main river | ... | ... | 455 | |
| | 18 | Just above cut | Head cut | 11·40 | 319 | |
| | 18 | K.P. 320 | Gh. Ind. | 11·43 | 468 | |
| | 18 | Awai inlets 1 kilometre D.S. of K.P. 470 channel flowing with River Atem | ... | ... | 48 | |
| | 19 | Atem, A | ... | ... | 128 | |
| | 21 | „ B | ... | ... | 102 | |
| | 21 | „ C | ... | ... | 114 | |
| | 11 | Mongalla | Mongalla | 11·30 | 830 | |
| | 22 | Awai inlets close to K.P. 360 | ... | ... | 266 | |
| | 23 | „ inlets near K.P. 405 | ... | ... | 62 | |
| | 23 | „ D.S. of inlet at K.P. 405 | ... | ... | 143 | |
| | 23 | „ smaller of double inlets | ... | ... | 65 | |
| | 23 | „ larger of double inlets | ... | ... | 206 | |
| | 23 | „ just above double inlets | ... | ... | 386 | |
| | 24 | „ D | ... | ... | 130 | |
| | 25 | „ D.S. of double inlets | Gha. Sh. | 11·31 | 168 | |
| Mar. | 7 | Near cut | Head cut | 11·20 | 336 | |
| | 7 | Ghaba el Inderab | Gh. Ind. | 11·22 | 360 | |
| | 7 | K.P. 320 | „ | 11·22 | 456 | |
| | 8 | „ 250 | ... | ... | 259 | |
| | 9 | „ 150 | ... | ... | 453 | 600 |
| | 9 | „ 185 | ... | ... | 434 | 600 |
| | 10 | „ 105 | ... | ... | 427 | 600 |
| | 11 | „ 50 | Buf. Cape | 11·53 | 350 | 600 |
| | 12 | „ 1 | Lake No | 13·61 | 346 | 600 |
| July | 1 | Just above new cut | Head cut | 11·21 | 322 | |
| Aug. | 14 | Aliab (Mongalla) 100 metres from mouth | ... | ... | 17 | |
| | 15 | Mongalla | Mongalla | 11·49 | 868 | |
| | 17 | „ | „ | 11·62 | 952 | |
| | 20 | Awai inlets | ... | ... | 62 | |
| | 21 | Awai No. 2 close to inlet near K.P. 470 | ... | ... | 128 | |
| | 22 | K.P. 320 | Gh. Ind. | 11·33 | 536 | |

TABLE III (*continued*).

| Date. | Site. | Gauge. Name. | Gauge. Reading. | Discharge. | Mongalla Discharge. |
|---|---|---|---|---|---|
| 1911 | | | | | |
| Oct. 4 | Just above new cut . . . | Head of cut | 11·31 | 357 | |
| 17 | 500 metres U.S. of K.P. 355 . . | Gh. Ind. | 11·34 | 614 | |
| Nov. 19 | Above K.P. 355 . . . . | ,, | 11·32 | 527 | |
| 1912 | | | | | |
| Feb. 1 | 300 metres D.S. of K.P. 355 . . | ... | ... | 486 | |
| 1 | 500 ,, ,, ,, 360 . . | ... | ... | 488 | |
| 1 | Just U.S. of K.P. 360 and 200 metres U.S. of Awai outlet . . | ... | ... | 4 | |
| 1 | 600 metres U.S. of K.P. 355 . . | ... | ... | 483 | |
| 3 | 1 kilometre D.S. of K.P. 340 . . | ... | ... | 476 | |
| 3 | U.S.K.P. 320 and 200 D.S. of point where the two branches meet again . . . . . . . | ... | ... | 435 | |
| 11 | About K.P. 3 . . . . . | Lake No | 13·58 | 360 | 550 |
| 21 | Gage's channel 300 metres upstream | Hil. Nuer | 10·96 | 13 | |
| 21 | 200 metres U.S. of K.P. 55 . . | ... | ... | 386 | 540 |
| 22 | 1 kilometre D.S. of K.P. 180 . . | ... | ... | 318 | 540 |
| 24 | Near K.P. 155 . . . . | ... | ... | 291 | 540 |
| 24 | K.P. 395 . . . . . . | ... | ... | 408 | |
| 26 | Bor . . . . . . . | Bor | 10·37 | 543 | 600 |
| 28 | 500 metres S. of K.P. 355 . . | ... | ... | 486 | |
| Apr. 10 | Mongalla . . . . . | Mongalla | 10·80 | 540 | |
| 10 | ,, . . . . . . | ,, | 10·80 | 522 | |
| 12 | Bor . . . . . . . | Bor | 10·18 | 508 | 520 |
| May 8 | ,, . . . . . . . | ,, | 10·26 | 522 | 550 |

[TABLE

TABLE 112.—DISCHARGE OBSERVATIONS TAKEN IN SEPTEMBER AND OCTOBER 1912.

| | Date. | Gauge. | | Width, m. | Area, $m^2$. | Greatest Depth, m. | Mean Depth, m. | Mean Velocity, m/s | Discharge, $m^3/s$. | Site. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1912 | | | | | | | | | |
| River Sobat . | Sept. 16 | Doleib Hill | 13·51 | 147 | 955 | 7·70 | 6·49 | 7·97 | 761 | |
| | 30 | ,, | 13·65 | 148 | 952 | 7·80 | 6·43 | ·845 | 805 | |
| | Oct. 18 | ... | ... | 130 | 761 | 7·60 | 5·97 | 1·021 | 776 | Just below Pibor junction. |
| | 18 | ... | ... | 85 | 575 | 9·90 | 6·77 | ·867 | 499 | R. Baro just above Pibor junction. |
| | 19 | Doleib Hill | 13·67 | 147 | 940 | 7·50 | 6·48 | ·864 | 814 | |
| | 26 | ... | ... | 38 | 112 | 4·00 | 2·94 | ·260 | 38 | Khor Filus at village near Abwong. |
| Bahr el Zeraf . | Sept. 29 | Zeraf mouth | 12·67 | 47·5 | 27·6 | 6·90 | 5·80 | ·516 | 142 | |
| Albert Nile . | Oct. 19 | Attigo | 12·92 | 27 | 67 | 3·80 | 2·47 | ·235 | 16 | Attigo Cut. |
| | 19 | ,, | 12·92 | 225 | 86 | 5·00 | 3·80 | ·277 | 24 | Abu Tong Cut. |
| | 19 | ,, | 12·92 | 72 | 223 | 4·40 | 3·10 | ·208 | 46 | K. Lolle D.S.K. 74. |

TABLE 113.—DISCHARGES TAKEN ON THE ALBERT NILE, 1912.

| Date. | | Site. | Discharge, m³/s. | Remarks. |
|---|---|---|---|---|
| July | 8 | Albert Nile below Lake No | 349 | |
| | 8 | „ „ above „ | 312 | Gauge 13·46. |
| | 8 | „ „ (K.P. 1) | 324 | |
| | 8 | „ „ ( „ 5) | 331 | Buffalo Cape 11·35. |
| | 8 | „ „ ( „ 10) | 322 | |
| | 7 | „ „ ( „ 15) | 342 | |
| | 7 | „ „ ( „ 20) | 325 | When the Sobat is in flood, from July on, there is backwater on the Albert Nile tail. |
| | 7 | „ „ ( „ 25) | 333 | |
| | 7 | „ „ ( „ 30) | 334 | |
| | 7 | „ „ ( „ 35) | 340 | |
| | 7 | „ „ ( „ 40) | 326 | |
| | 7 | „ „ ( „ 45) | 333 | |
| | 7 | „ „ (Buffalo Cape) | 349 | |
| August | 11 | „ „ (K.P. 50) | 344 | Buffalo Cape 11·46. |
| | 10 | „ „ ( „ 55) | 357 | |
| | 10 | „ „ ( „ 60) | 362 | |
| | 10 | „ „ ( „ 65) | 372 | |
| | 10 | „ „ ( „ 70) | 365 | |
| | 10 | „ „ ( „ 75) | 372 | |
| | 10 | „ „ ( „ 80) | 358 | |
| | 9 | „ „ ( „ 85) | 384 | |
| | 9 | „ „ ( „ 90) | 368 | |
| | 9 | „ „ ( „ 95) | 371 | |
| | 9 | „ „ ( „ 100) | 383 | |
| | 9 | „ „ ( „ 105) | 376 | |
| September | 8 | „ „ ( „ 110) | 395 | |
| | 8 | „ „ ( „ 115) | 403 | |
| | 7 | „ „ ( „ 120) | 405 | |
| | 7 | „ „ ( „ 125) | 412 | |
| | 7 | „ „ ( „ 130) | 408 | |
| | 6 | „ „ ( „ 135) | 399 | |
| | 6 | „ „ ( „ 140) | 388 | |
| | 6 | „ „ ( „ 145) | 389 | |
| | 6 | „ „ ( „ 150) | 407 | |
| | 5 | „ „ ( „ 155) | 417 | |
| | 5 | „ „ ( „ 160) | 409 | |
| | 5 | „ „ ( „ 165) | 334 | |
| | 5 | „ „ ( „ 170) | 362 | |
| | 4 | „ „ ( „ 175) | 423 | Buffalo Cape 11·50. |
| | 4 | „ „ ( „ 180) | 421 | |
| | 4 | „ „ ( „ 185) | 400 | |
| | 4 | „ „ ( „ 190) | 419 | |
| | 4 | „ „ ( „ 195) | 493 | |
| | 12 | | | Buffalo Cape 11·53. |

K.P. = Kilometres measured up the Albert Nile from Lake No.

27. **The Discharges of the Nile and its Tributaries.**—Reference should be made to Tables 98 to 109, which embody the results of an exhaustive examination of the observed discharges, the cross sections, the gauges of the Nile Valley, and the calculated discharge tables made for these gauges. Some of these tables are founded on only two or three discharges, but they have been prepared with the greatest care and referred to all the existing gauge observations, and are good working tables which can be modified and improved as time places more information at our disposal. Until then they may be used as about the best approximations available to-day.

One word of warning is necessary, however: the Nile for most of its course runs in a bed of sand or sandy mud which is particularly liable to change. During a high flood it is scoured out, and after a low or particularly muddy one silted up, and allowance must be made for this tendency in using the tables. Useful enough results will be obtained by adding the average amount of scour to or subtracting the average amount of silting from the actual gauge reading, before calculating the discharge. For this purpose it would be well indeed if at least once a month a section were taken opposite every important gauge in both Egypt and the Sudan. A discharge measurement at the same time would be invaluable, but in any case the section should be made.

Egypt is interested during low supply in discharges rather than levels, but in flood the contrary is the case. It is more interested in making the most of the low supply in a poor year than in a good year, and we select the period from July 1911 to July 1912 to illustrate a period of low supply. In flood the chief interest lies in the dangers to the banks that may accompany a high and long flood: the difficulties of distribution consequent on a poor flood are small in these days of barrages. There has been no really high flood within the experience of the present generation of engineers. Though those of 1892 and 1894 were high, they were not within 70 centimetres at Cairo of those of 1874 and 1878, and in the latter year the gauge would have read higher still but for the fact that the left bank breached upstream of Giza and the valley was awash from there to the Barrage. We select the flood of 1908 as the nearest recent flood to that of 1874, but it should be remembered that the maximum readings at Roda in the two years were 20·15 metres and 21·4 metres respectively, although in 1874 the basins took a larger portion of the water than in 1908.

There are two methods of studying the flow of a fluid. In the former we fix on a number of points and study what happens at each; in the latter we fix on a definite volume of the fluid and follow it in its wanderings. Both methods have their uses. The former is the easier when it is a question of collecting and tabulating data; the latter when we wish to study them. We illustrate the former by Table 114, which may be looked

# CROSS SECTIONS OF THE NILE & ITS TRIBUTARIES

*Horizontal Scale 1 : 2.000 Vertical Scale 1 : 500*


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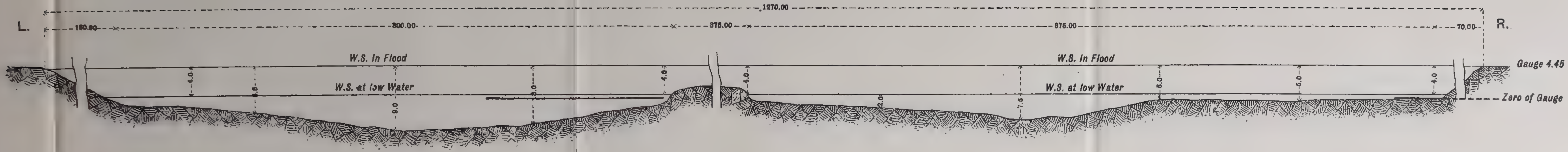
PLATE V.

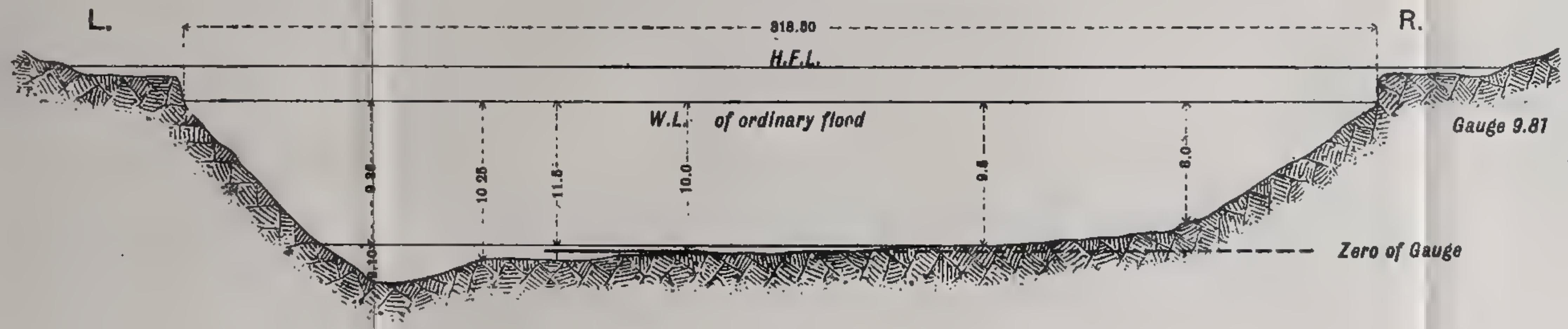
# CROSS SECTIONS OF THE NILE & ITS TRIBUTARIES

*Horizontal Scale 1 : 2.000 Vertical Scale 1 : 500*

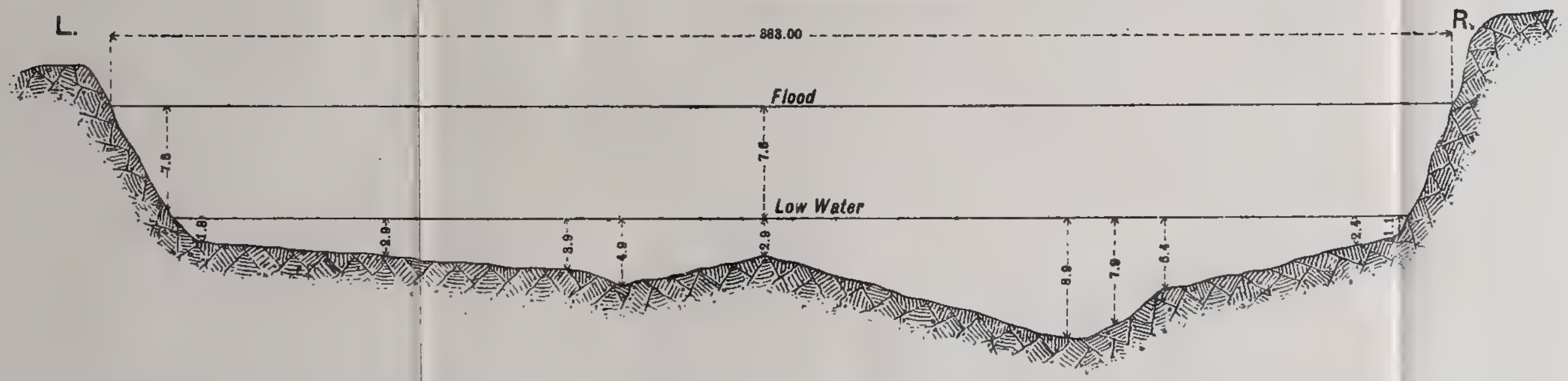
## No. 14. *White Nile at Duem.*




## No. 17. *Blue Nile at Wad Medani*




## No. 18. *Blue Nile at Khartoum*




*To face p. 212.* Willcocks and Craig Egyptian Irrigation.

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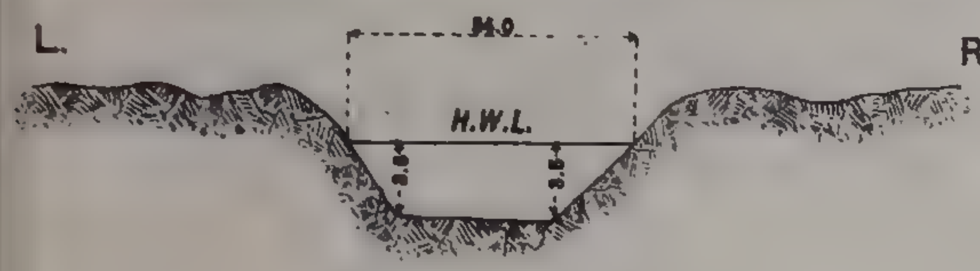
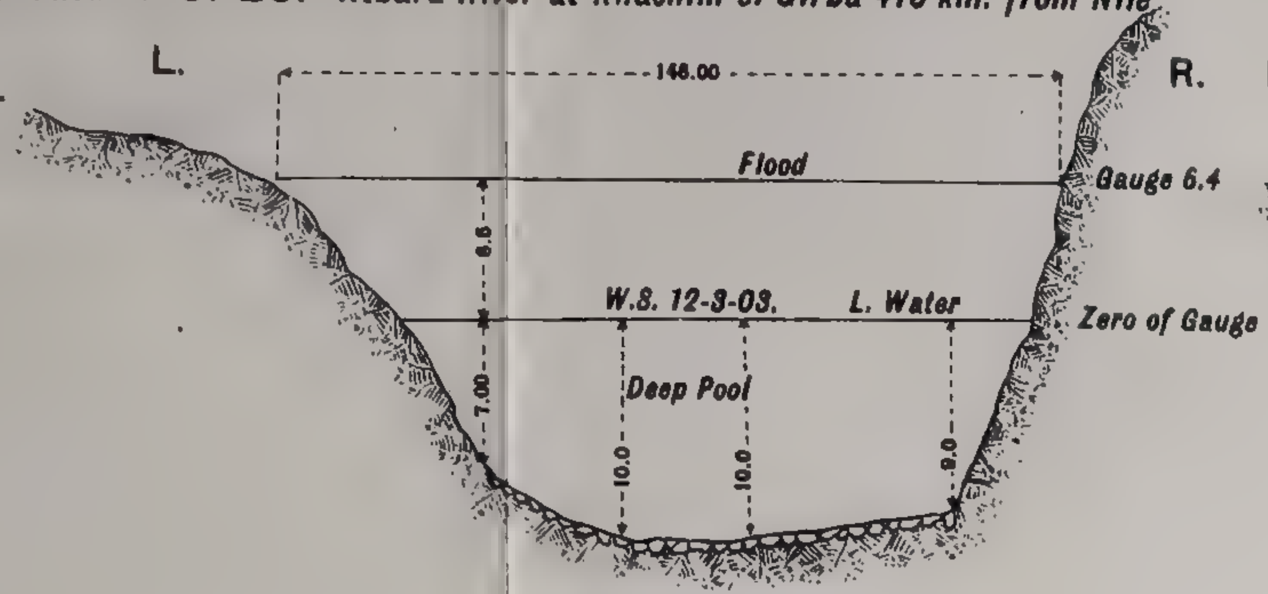
# CROSS SECTIONS OF THE NILE & ITS TRIBUTARIES

Horizontal Scale 1 : 2.000 Vertical Scale 1 : 500

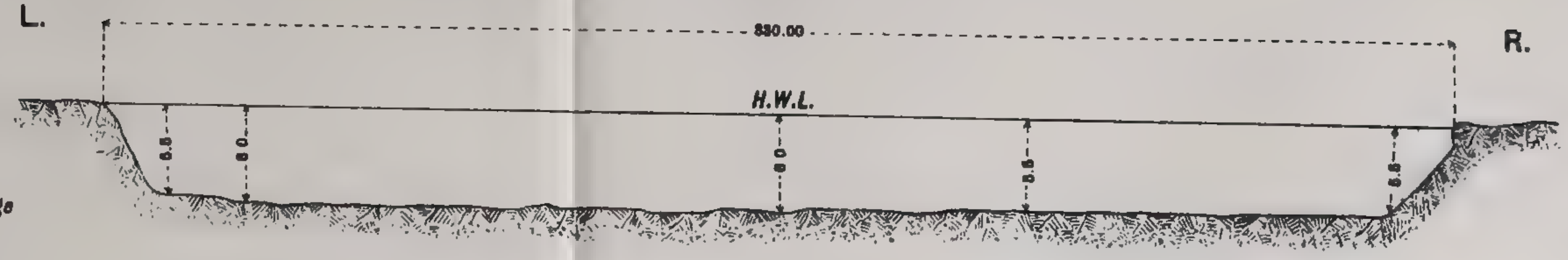
**No. 19.** *River Rahad at Khor Abou Seghira 20 km. above the Nile Junction*



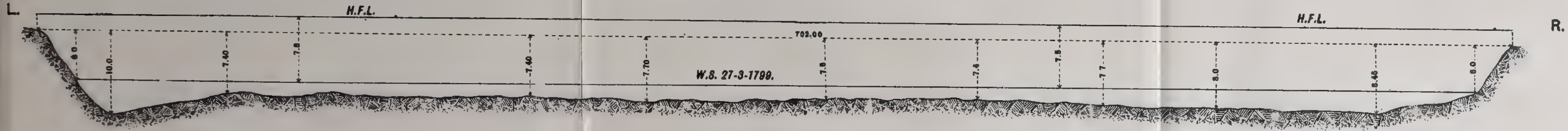

**No. 20.** *Atbara River at Khashim el Girba 410 km. from Nile*



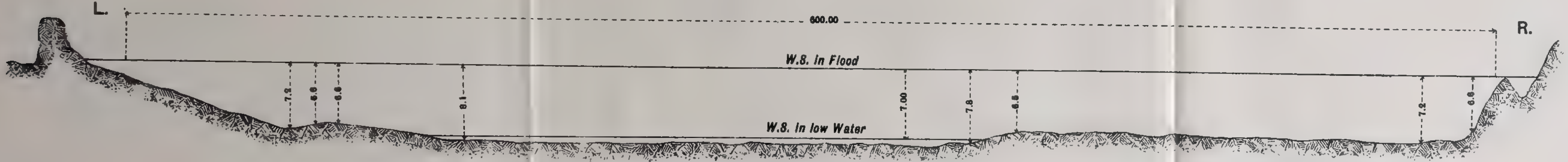

**No. 21.** *Atbara River at Khor Abadar 25 km. from Nile*



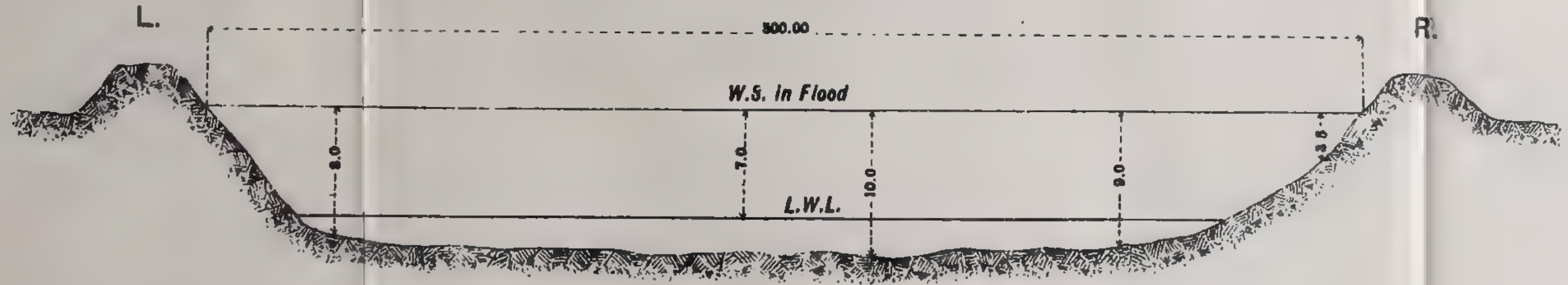

**No. 22.** *Nile at Manfalout*




**No. 23.** *Rosetta Branch at Khatatba*




**No. 24.** *Damietta Branch at Benha*



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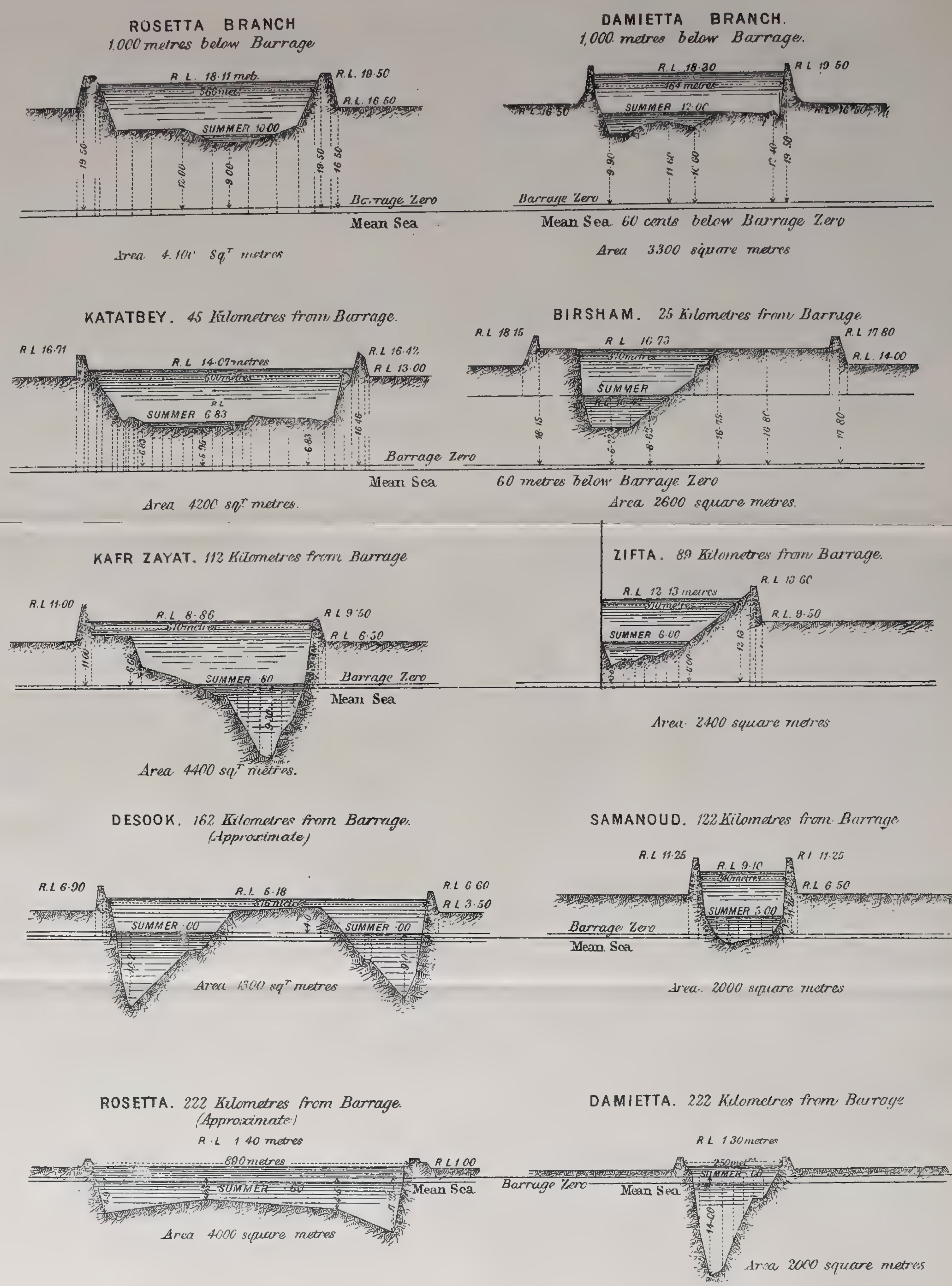
# CROSS SECTIONS OF THE NILE BRANCHES.

Scale, Long$^l$ $\frac{1}{12000}$
Vert$^l$ $\frac{1}{600}$

1888.



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on as containing twelve instantaneous pictures of the behaviour of the river and its tributaries at the mean dates of the months. We illustrate the latter by Table 71, which gives the life-histories of twelve volumes of water setting out from Lake Albert on the first of each month. This table is not so accurate as the other: collection and tabulation of data are easy; their discussion hard. But it gives us an idea of the individuality of the great river in a way that the other cannot do. The difference between the tables is that between a book of photographs and a cinematograph.

On 17th March 1911, 720 cubic metres per second left Lake Albert. By the 25th this water reached Mongalla, where it was now 620 cubic metres per second. In four days it reached the head of the Zeraf; 100 cubic metres per second passed into that river, and the balance took the longer route though the Sudd region. At Lake No the latter delivered 360 cubic metres per second and received a small addition from the Bahr el Ghazal. At the tail of the Zeraf the two waters met again on about 9th April, when their combined volumes gave a discharge of 500 cubic metres per second. Allowing 20 cubic metres per second to the Ghazal, the balance, or 480 cubic metres per second, came from Mongalla. The Sobat supplied 60 cubic metres, and the total at Malakal at the head of the White Nile was raised to 560 cubic metres per second. The volume passing Malakal was made up as follows:—

| | |
|---|---|
| Albert Nile . . . . . . | 89 per cent. |
| Sobat . . . . . . | 11 „ |

Of the 620 cubic metres per second which passed Mongalla, 480 cubic metres, or 77 per cent., passed on to the White Nile. In the Sudd region 140 cubic metres per second, or 23 per cent., were lost. It is very evident that the eight years during which the Albert Nile has been kept clear of sudd has greatly improved the channel as compared to what it was between 1900 and 1904 when all the early observations were made.

Between Malakal and Khartoum the White Nile lost heavily by evaporation, but was fed out of the very extensive falling trough, which is here rather like a reservoir; and of the 560 cubic metres per second entering the White Nile, the discharge delivered at its tail at Khartoum on the 8th May was only 40 cubic metres less, or 520 cubic metres per second.

At Khartoum the Blue Nile joined the White Nile, and on the 8th May was adding its quota of 180 cubic metres per second, bringing the total of the Main Nile at its head to 700 cubic metres per second. The 700 cubic metres per second in the Main Nile might be considered as made up as follows:—

| | | |
|---|---|---|
| Albert Nile, 66 per cent. | } White Nile, 74 per cent. |
| Sobat, 8 „ | } |
| Blue Nile, 26 „ | |

(There have been years when the Blue Nile has fallen to nearly zero at Khartoum, when the whole supply in the Main Nile has come from the White Nile.)

Wadi Halfa was reached on the 24th May, when the discharge had fallen to 635 cubic metres per second, the minimum for the year.

After this date early freshets down the Blue Nile and an early flush down the Atbara swelled the volume of the river by 9th June to 840 cubic metres per second.

We now take the year 1912. The water which left Lake Albert on the 17th March reached Mongalla on the 25th, where it was 520 cubic metres per second. In four days it reached the head of the Zeraf; about 80 cubic metres passed into that river, and the balance remained in the Albert Nile. At Lake No the latter delivered 340 cubic metres per second, and received some 20 cubic metres per second from the Gazelle River. At the tail of the Zeraf the two waters met again about 9th April, where their combined discharges amounted to 430 cubic metres per second, of which 20 came from the Gazelle. The Sobat supplied 60 cubic metres per second, and the total at Malakal at the head of the White Nile was 490 cubic metres per second. The quantity of water lost in the Sudd region was (520 − 410 or) 110 cubic metres per second, or about one-fifth of the water passing Mongolla. The discharge delivered at Khartoum on the 8th May was 430 cubic metres per second. At Khartoum the Blue Nile joined the White Nile and added 60 cubic metres per second, making the total discharge of the Main Nile at its head 490 cubic metres per second. Wadi Halfa was reached on the 24th May, where the discharge was 440 cubic metres per second.

An importance is frequently claimed for the early discharges of the Sobat that they do not possess. They may reach the White Nile before the corresponding discharges reach Roseires on the Blue Nile, but they loiter so long between Malakal and Khartoum that the Blue Nile discharges are already some fourteen to twenty days on their way down the main river to Egypt. It is far different with the early rains in Abyssinia in the catchment basins of the Blue Nile and the Atbara. They may not be heavy, but any contribution that reaches the river comes at a time when it is very badly wanted.

To turn now to the flood of 1911, we notice that the maximum gauge reading occurred at Wadi Halfa about 13th September. Now, since the maxima of velocity, discharge, and gauge do not come simultaneously, but follow one another in that order, the maximum discharge must have occurred about 12th September. We can therefore interpolate and follow the movement easily.

The water which left Lake Albert on the 18th July arrived at Mongalla on 25th July, when it amounted to 818 cubic metres. Loss in

the swamps reduced this by 9th August to 486 cubic metres per second at the tail of the Albert Nile, so that at least 59 per cent. was lost to the river. The Sobat added 646, but as the basin upstream of Malakal was now filling up rapidly, some 123 cubic metres per second had to be left behind, and 1009 flowed away down the White Nile. At this time (3rd September) the Blue Nile was still rising slowly and compelling the White Nile to fill up its trough, and of the 1009 cubic metres per second that passed Malakal only some 297 passed Khartoum into the main stream. The Blue Nile in full flood was discharging 7954 cubic metres per second, and the joint river 8251. The trough from Khartoum northwards was full, and any addition to its contents passed down the river undiminished. Consequently we can understand how the 3240 cubic metres per second added by the Atbara caused at Wadi Halfa a rise of 50 centimetres in three days' time, whereas the 2900 added by the Atbara in the middle of August was largely expended in filling up the trough. It is these late rises of the Atbara that are likely to give trouble in high floods, for then the basins are full in Upper Egypt and little artificial regulation can be carried out, while the brimming trough passes on the flush with great rapidity. The combined volume passing Berber on 5th September amounted to some 11,500 cubic metres per second, though it is not possible to obtain great exactitude in this figure, as an error of a fraction of a day would make a considerable difference in the case of a torrential river like the Atbara. At Wadi Halfa—reached on 12th September—the flush had flattened out and the maximum was 10,800 cubic metres per second, which passed on to Egypt and reached the Delta Barrage about 21st September, having flattened out still further on the way. The maximum due to the discharge of the basins did not reach Roda till 21st October.

Had the flush due to the Atbara reached Cairo simultaneously with that due to the discharge of the basins, as was the case in 1874, 1878 and 1894, Roda gauge would have risen some 50 centimetres more than it actually did. If the flush which gave the maximum in the end of September of 1908 had been three weeks later, as it well might have been, levels approaching those of 1878 would have been the result.

[Table

TABLE 114.—DISCHARGES OF THE NILE AND ITS TRIBUTARIES FOR 1911 (in cubic metres per second).

| Month. | Albert Nile | | | | Gazelle River and No to Malakal Reach. | Sobat River. | White Nile | | Blue Nile at Khartoum. | Main Nile at Khartoum. | Atbara River. | Main Nile | | Percentage of Column 1 at Column 4. | Percentage of Column 4 in Column 7. | Percentage of Column 8 in Column 10. | Percentage of Column 9 in Column 10. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | at Mongalla. | at Lake No.* | Zeraf River. | Total, Albert Nile at Tail. | | | at Malakal. | at Khartoum. | | | | at Kareima. | at Wadi Halfa. | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) |
| January . . . | 692 | 360 | 150 | 510 | 99 | 503 | 1112 | 1219 | 491 | 1710 | 31 | 1673 | 1773 | 74 | 46 | 71 | 29 |
| February . . | 624 | 360 | 150 | 510 | 67 | 133 | 710 | 1012 | 305 | 1313 | 12 | 1246 | 1376 | 82 | 73 | 77 | 23 |
| March . . . | 602 | 360 | 158 | 498 | 11 | 96 | 605 | 618 | 210 | 829 | 1 | 842 | 924 | 83 | 83 | 77 | 23 |
| April . . . | 616 | 360 | 96 | 456 | 49 | 48 | 553 | 525 | 157 | 681 | 0 | 677 | 738 | 74 | 83 | 77 | 23 |
| May . . . | 692 | 360 | 73 | 433 | – 2 | 138 | 569 | 534 | 209 | 742 | 0 | 658 | 672 | 63 | 78 | 72 | 28 |
| June . . . | 684 | 360 | 80 | 440 | – 104 | 395 | 731 | 618 | 395 | 1013 | 76 | 870 | 806 | 65 | 60 | 61 | 39 |
| July . . . | 765 | 360 | 100 | 460 | – 106 | 565 | 919 | 653 | 1773 | 2426 | 484 | 2058 | 1469 | 60 | 50 | 27 | 73 |
| August . . . | 805 | 360 | 130 | 490 | – 132 | 665 | 1023 | 135 | 6667 | 6800 | 1763 | 7301 | 6487 | 61 | 49 | 2 | 98 |
| September . . | 935 | 360 | 161 | 521 | – 156 | 753 | 1118 | 435 | 7390 | 7825 | 1528 | 9918 | 9558 | 56 | 46 | 6 | 94 |
| October . . . | 905 | 360 | 135 | 495 | – 87 | 760 | 1168 | 1497 | 3163 | 4660 | 247 | 5284 | 5782 | 57 | 42 | 32 | 68 |
| November . . | 923 | 360 | 130 | 480 | – 27 | 735 | 1188 | 1060 | 1630 | 2690 | 125 | 2827 | 3059 | 52 | 40 | 40 | 60 |
| December . . | 800 | 360 | 110 | 470 | 69 | 505 | 1044 | 966 | 893 | 1860 | 46 | 1961 | 2069 | 59 | 45 | 52 | 48 |
| Year . . . | 754 | 360 | 123 | 481 | – 26 | 441 | 896 | 773 | 1949 | 2721 | 362 | 2950 | 2880 | 64 | 53 | 27 | 63 |

From 1908 to 1911 the discharge of the Albert Nile at Lake No was approximatively 360 cubic metres per second every day of the year.

* Approximate, the Sobat throws backwater on the Albert Nile at Lake No in all but the low stages of the river.

TABLE 115.—DISCHARGES OF THE NILE AND ITS TRIBUTARIES FOR 1912 (in cubic metres per second).

| Month. | Albert Nile | | | | Gazelle River and No to Malakal Reach. | Sobat River. | White Nile | | Blue Nile at Khartoum. | Main Nile at Khartoum. | Atbara River. | Main Nile at Wadi Halfa. | Percentage of Column 1 at Column 4. | Percentage of Column 4 in Column 7. | Percentage of Column 8 in Column 10. | Percentage of Column 9 in Column 10. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | at Mongalla. | at Lake No.* | Zeraf River. | Total, Albert Nile at Tail. | | | at Malakal. | at Khartoum. | | | | | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
| January | 593 | 360 | 96 | 456 | 51 | 222 | 729 | 780 | 470 | 1250 | ... | 1470 | 77 | 62 | 62 | 38 |
| February | 541 | 360 | 91 | 451 | 13 | 136 | 600 | 630 | 270 | 900 | ... | 1000 | 83 | 71 | 70 | 30 |
| March | 517 | 350 | 84 | 434 | 7 | 85 | 526 | 500 | 200 | 700 | ... | 690 | 84 | 82 | 71 | 29 |
| April | 540 | 340 | 75 | 415 | 23 | 52 | 490 | 460 | 100 | 560 | ... | 550 | 77 | 85 | 82 | 18 |
| May | 580 | 330 | 73 | 403 | − 17 | 68 | 454 | 430 | 60 | 490 | ... | 463 | 70 | 89 | 88 | 12 |
| June | 580 | 330 | 80 | 400 | − 28 | 221 | 593 | 250 | 500 | 750 | 800 | 430 | 70 | 67 | 33 | 67 |
| July | 808 | 320 | 103 | 423 | − 42 | 455 | 836 | 450 | 2050 | 2500 | 800 | 1330 | 52 | 51 | 18 | 82 |
| August | 1097 | 320 | 137 | 457 | − 27 | 642 | 1072 | 0 | 6000 | 6000 | 2050 | 7480 | 41 | 43 | ... | 100 |
| September | 1223 | 330 | 140 | 470 | − 25 | 762 | 1207 | 1400 | 4300 | 5700 | 1000 | 7380 | 39 | 39 | 25 | 75 |
| October | 823 | 340 | 129 | 469 | − 8 | 806 | 1267 | 1270 | 1730 | 3000 | 140 | 4230 | 57 | 37 | 42 | 58 |
| November | 792 | 360 | 122 | 482 | − 9 | 764 | 1237 | 1120 | 890 | 2010 | 60 | 2370 | 61 | 39 | 56 | 44 |
| December | 738 | 360 | 120 | 480 | 69 | 512 | 1061 | 990 | 480 | 1470 | 30 | 1730 | 65 | 45 | 67 | 33 |
| Year | 736 | 342 | 104 | 445 | 0 | 394 | 839 | 690 | 1421 | 2111 | 407 | 2427 | 60 | 53 | 33 | 67 |

* Approximate. See note, Table 114.

We add an explanation of Table 114:—

In January the Albert Nile at Mongalla in the south was discharging 690 cubic metres per second, and aided by the Gazelle was discharging at its tail at Malakal 610 cubic metres. The Sobat was adding 500, so that the White Nile at its head was discharging 1110 cubic metres per second. At its tail in Khartoum, aided by its own emptying reservoir, it was discharging 1220 cubic metres. The Blue Nile at Khartoum was adding 490, so that the Main Nile at its head was discharging 1710 cubic metres per second. The Atbara was giving 30 cubic metres. The discharge of the Main Nile at Wadi Halfa where it entered Egypt was 1770 cubic metres per second. For certain of the months we tabulate the information in this form:—

1911. (Discharges in cubic metres per second.)

| River and Locality. | Jan. | April. | August. | Sept. | Oct. | Dec. |
|---|---|---|---|---|---|---|
| Albert Nile at Mongalla . | 690 | 620 | 810 | 940 | 910 | 800 |
| Albert Nile at Malakal . . | 610 | 500 | 350 | 370 | 410 | 530 |
| Sobat River . . . . | 500 | 50 | 670 | 750 | 760 | 510 |
| White Nile at Malakal . | 1110 | 550 | 1020 | 1120 | 1170 | 1040 |
| White Nile at Khartoum . | 1220 | 520 | 130 | 440 | 1500 | 970 |
| Blue Nile at Khartoum . . | 490 | 160 | 6670 | 7390 | 3160 | 890 |
| Main Nile at Khartoum . | 1710 | 680 | 6800 | 7830 | 4660 | 1860 |
| Atbara River . . . | 30 | 0 | 1760 | 1530 | 250 | 50 |
| Main Nile at Wadi Halfa . | 1770 | 740 | 6490 | 9560 | 5780 | 2070 |

In CHAPTER III. will be given full reasons why the discharges increase and decrease in this extraordinary way.

[TABLE

TABLE 116.—DISCHARGE OF THE ALBERT AND WHITE NILES (in cubic metres per second).
Means of the six years 1906–1911.

| Month. | At Mongalla. | At Lake No.* | Zeraf River. | Total Albert Nile at Tail. | Gazelle River and Lake No to Malakal Reach. | Sobat River. | White Nile at Malakal. | Percentage of Column 1 in Column 4. | Percentage of Column 7 in Column 4. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | |
| January | 923 | 350 | 160 | 510 | 110 | 430 | 1050 | 55 | 49 | Column 8 gives the percentage of the Albert Nile water at Mongalla which reaches the White Nile. |
| February | 841 | 350 | 150 | 500 | 90 | 140 | 730 | 60 | 69 | |
| March | 792 | 350 | 130 | 480 | 40 | 90 | 610 | 60 | 80 | |
| April | 835 | 350 | 100 | 450 | 40 | 80 | 570 | 54 | 79 | |
| May | 949 | 350 | 80 | 430 | ... | 170 | 600 | 45 | 71 | Column 9 gives the percentage of Albert Nile water in the water which passes Malakal. |
| June | 935 | 350 | 80 | 430 | – 50 | 380 | 760 | 46 | 57 | |
| July | 1028 | 350 | 100 | 450 | – 60 | 550 | 940 | 45 | 49 | |
| August | 1219 | 350 | 130 | 480 | – 80 | 660 | 1060 | 40 | 45 | Practically the Albert Nile gives half and the Sobat half; the Albert Nile gives most of the supply in summer and the Sobat in flood. |
| September | 1480 | 350 | 150 | 500 | – 110 | 760 | 1170 | 34 | 43 | |
| October | 1135 | 350 | 170 | 520 | – 70 | 830 | 1280 | 46 | 41 | |
| November | 1277 | 350 | 170 | 520 | – 70 | 830 | 1280 | 41 | 41 | |
| December | 984 | 350 | 160 | 510 | – 20 | 710 | 1200 | 52 | 42 | |
| Year | 1033 | 350 | 140 | 490 | – 20 | 470 | 940 | 48 | 51 | |

* Approximate. See note, Table 114.

TABLE 117.—ZERAF RIVER DISCHARGE AT ITS TAIL.
(Ten-day means, 1906–1911. Cubic metres per second.)

| Mean Date. | | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | Means, 1906–1911. | 1912. |
|---|---|---|---|---|---|---|---|---|---|
| January | 5 | 130 | 188 | 172 | 152 | 200 | 150 | 165 | |
| | 15 | 125 | 187 | 167 | 152 | 195 | 150 | 163 | 96 |
| | 25 | 125 | 186 | 153 | 152 | 188 | 150 | 159 | |
| February | 5 | 120 | 183 | 145 | 152 | 182 | 150 | 155 | |
| | 15 | 120 | 173 | 136 | 152 | 175 | 150 | 151 | 91 |
| | 25 | 110 | 164 | 127 | 152 | 178 | 150 | 146 | |
| March | 5 | 110 | 158 | 120 | 152 | 155 | 145 | 140 | |
| | 15 | 110 | 151 | 113 | 152 | 130 | 140 | 133 | 84 |
| | 25 | 105 | 148 | 102 | 149 | 102 | 130 | 123 | |
| April | 5 | 105 | 145 | 92 | 144 | 77 | 115 | 113 | |
| | 15 | 105 | 141 | 80 | 135 | 60 | 90 | 102 | 75 |
| | 25 | 100 | 139 | 72 | 120 | 55 | 84 | 95 | |
| May | 5 | 95 | 136 | 67 | 100 | 56 | 70 | 87 | |
| | 15 | 95 | 133 | 64 | 82 | 57 | 72 | 84 | 73 |
| | 25 | 90 | 128 | 62 | 74 | 58 | 78 | 82 | |
| June | 5 | 90 | 122 | 61 | 70 | 59 | 90 | 82 | |
| | 15 | 95 | 123 | 62 | 67 | 61 | 95 | 84 | 80 |
| | 25 | 100 | 127 | 68 | 74 | 65 | 100 | 89 | |
| July | 5 | 110 | 132 | 78 | 84 | 70 | 103 | 96 | |
| | 15 | 115 | 136 | 92 | 97 | 77 | 104 | 103 | 103 |
| | 25 | 125 | 143 | 103 | 110 | 85 | 104 | 112 | |
| August | 5 | 135 | 149 | 113 | 122 | 95 | 104 | 120 | |
| | 15 | 140 | 155 | 122 | 138 | 107 | 112 | 129 | 137 |
| | 25 | 150 | 162 | 132 | 152 | 120 | 118 | 139 | |
| September | 5 | 160 | 169 | 140 | 162 | 137 | 128 | 149 | |
| | 15 | 170 | 173 | 148 | 170 | 156 | 132 | 158 | 140 |
| | 25 | 175 | 178 | 152 | 176 | 170 | 134 | 164 | |
| October | 5 | 180 | 182 | 156 | 182 | 172 | 135 | 168 | |
| | 15 | 185 | 184 | 158 | 190 | 175 | 135 | 171 | 129 |
| | 25 | 185 | 186 | 159 | 192 | 175 | 135 | 172 | |
| November | 5 | 190 | 186 | 159 | 195 | 175 | 135 | 173 | |
| | 15 | 190 | 186 | 157 | 196 | 175 | 130 | 172 | 122 |
| | 25 | 190 | 186 | 156 | 197 | 175 | 125 | 171 | |
| December | 5 | 190 | 185 | 155 | 198 | 175 | 120 | 171 | |
| | 15 | 190 | 183 | 152 | 198 | 162 | 110 | 166 | 120 |
| | 25 | 190 | 181 | 150 | 198 | 150 | 100 | 162 | |
| Means | | 136 | 158 | 121 | 144 | 128 | 120 | 135 | 105 |

TABLE 118.—SOBAT RIVER DISCHARGES AT ITS TAIL AT DOLEIB HILL. 1906–1907 FROM DOLEIB HILL GAUGE DISCHARGE CURVE. 1908–1912 FROM ACTUAL OBSERVATION.

| Mean Date. | | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | Mean, 1906–1911. | 1912. |
|---|---|---|---|---|---|---|---|---|---|
| January | 5 | 343 | 325 | 280 | 734 | 980 | 690 | 559 | |
| | 15 | 250 | 220 | 226 | 565 | 840 | 550 | 442 | 222 |
| | 25 | 191 | 169 | 176 | 367 | 660 | 275 | 306 | |
| February | 5 | 138 | 135 | 130 | 220 | 390 | 178 | 198 | |
| | 15 | 107 | 117 | 107 | 126 | 230 | 127 | 136 | 136 |
| | 25 | 112 | 113 | 55 | 94 | 160 | 95 | 105 | |
| March | 5 | 140 | 120 | 44 | 114 | 100 | 85 | 101 | |
| | 15 | 112 | 105 | 23 | 110 | 80 | 95 | 88 | 85 |
| | 25 | 102 | 89 | 31 | 123 | 80 | 110 | 88 | |
| April | 5 | 105 | 83 | 21 | 146 | 75 | 73 | 84 | |
| | 15 | 88 | 105 | 35 | 162 | 70 | 40 | 83 | 52 |
| | 25 | 70 | 116 | 35 | 176 | 70 | 30 | 83 | |
| May | 5 | 60 | 83 | 72 | 219 | 95 | 80 | 101 | |
| | 15 | 144 | 77 | 167 | 310 | 146 | 140 | 164 | 68 |
| | 25 | 255 | 172 | 173 | 366 | 260 | 195 | 237 | |
| June | 5 | 358 | 294 | 186 | 432 | 366 | 248 | 314 | |
| | 15 | 390 | 378 | 227 | 569 | 445 | 308 | 386 | 221 |
| | 25 | 460 | 430 | 261 | 621 | 502 | 362 | 439 | |
| July | 5 | 520 | 477 | 430 | 650 | 544 | 424 | 507 | |
| | 15 | 554 | 542 | 483 | 680 | 577 | 480 | 553 | 455 |
| | 25 | 592 | 583 | 526 | 706 | 607 | 536 | 592 | |
| August | 5 | 630 | 620 | 562 | 746 | 632 | 590 | 630 | |
| | 15 | 657 | 657 | 587 | 772 | 657 | 646 | 663 | 642 |
| | 25 | 694 | 701 | 572 | 810 | 682 | 670 | 688 | |
| September | 5 | 741 | 708 | 607 | 862 | 708 | 692 | 720 | |
| | 15 | 760 | 729 | 620 | 909 | 732 | 720 | 745 | 762 |
| | 25 | 776 | 746 | 647 | 996 | 758 | 740 | 777 | |
| October | 5 | 803 | 744 | 688 | 1071 | 782 | 756 | 807 | |
| | 15 | 815 | 763 | 752 | 1158 | 805 | 764 | 843 | 806 |
| | 25 | 820 | 770 | 791 | 1121 | 830 | 760 | 849 | |
| November | 5 | 827 | 776 | 818 | 1126 | 850 | 752 | 858 | |
| | 15 | 833 | 650 | 825 | 1036 | 865 | 736 | 824 | |
| | 25 | 833 | 590 | 815 | 1013 | 880 | 716 | 808 | |
| December | 5 | 802 | 467 | 822 | 994 | 880 | 638 | 767 | |
| | 15 | 770 | 349 | 825 | 1004 | 875 | 516 | 723 | |
| | 25 | 626 | 263 | 811 | 994 | 870 | 360 | 654 | |
| Means | | 458 | 396 | 401 | 614 | 530 | 422 | 470 | ... |

TABLE 119.—WHITE NILE DISCHARGES AT MALAKAL
(in cubic metres per second.)

| Month. | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | Mean, 1906–1910. | 1912. |
|---|---|---|---|---|---|---|---|---|
| January | 900 | 910 | 780 | 1140 | 1400 | 1110 | 1050 | 730 |
| February | 660 | 670 | 640 | 750 | 930 | 710 | 730 | 600 |
| March | 650 | 640 | 550 | 610 | 660 | 600 | 610 | 530 |
| April | 590 | 620 | 510 | 660 | 530 | 550 | 570 | 490 |
| May | 550 | 630 | 540 | 730 | 570 | 570 | 600 | 450 |
| June | 790 | 760 | 670 | 870 | 770 | 730 | 760 | 590 |
| July | 960 | 930 | 910 | 1000 | 920 | 920 | 940 | 840 |
| August | 1080 | 1070 | 1050 | 1160 | 1040 | 1020 | 1060 | 1070 |
| September | 1200 | 1160 | 1170 | 1400 | 1160 | 1120 | 1170 | 1210 |
| October | 1270 | 1200 | 1240 | 1700 | 1230 | 1170 | 1280 | 1270 |
| November | 1280 | 1190 | 1290 | 1590 | 1270 | 1190 | 1280 | ... |
| December | 1250 | 1040 | 1290 | 1530 | 1280 | 1040 | 1200 | ... |
| Year | 940 | 900 | 890 | 1100 | 980 | 900 | 940 | ... |

As calculated by the Irrigation Department.
See also page 279.

TABLE 120.—WHITE NILE DISCHARGES AT MALAKAL.
(Ten-day means. Cubic metres per second.)

| Mean Date. | | 1906. | 1907. | 1908. | 1909. | 1910. | 1911. | Mean, 1906–1910. | 1912. |
|---|---|---|---|---|---|---|---|---|---|
| January | 5 . | 1015 | 1042 | 855 | 1244 | 1490 | | 1146 | |
| | 15 . | 910 | 898 | 776 | 1165 | 1428 | 1112 | 1054 | 729 |
| | 25 . | 792 | 789 | 716 | 1007 | 1285 | | 926 | |
| February | 5 . | 689 | 702 | 680 | 850 | 1098 | | 804 | |
| | 15 . | 636 | 665 | 652 | 736 | 910 | 710 | 720 | 600 |
| | 25 . | 647 | 655 | 605 | 654 | 783 | | 667 | |
| March | 5 . | 702 | 665 | 584 | 634 | 702 | | 652 | |
| | 15 . | 644 | 639 | 538 | 610 | 660 | 605 | 617 | 526 |
| | 25 . | 618 | 608 | 521 | 583 | 616 | | 591 | |
| April | 5 . | 629 | 586 | 506 | 616 | 544 | | 577 | |
| | 15 . | 594 | 629 | 515 | 682 | 523 | 553 | 580 | 490 |
| | 25 . | 555 | 655 | 500 | 696 | 519 | | 575 | |
| May | 5 . | 538 | 610 | 512 | 699 | 510 | | 565 | |
| | 15 . | 575 | 583 | 567 | 730 | 558 | 569 | 594 | 454 |
| | 25 . | 649 | 600 | 553 | 766 | 657 | | 641 | |
| June | 5 . | 738 | 699 | 581 | 812 | 723 | | 706 | |
| | 15 . | 794 | 773 | 657 | 869 | 776 | 731 | 771 | 593 |
| | 25 . | 853 | 825 | 786 | 931 | 812 | | 820 | |
| July | 5 . | 922 | 876 | 855 | 970 | 879 | | 899 | |
| | 15 . | 955 | 940 | 908 | 1000 | 925 | 919 | 944 | 836 |
| | 25 . | 1000 | 967 | 951 | 1036 | 961 | | 980 | |
| August | 5 . | 1039 | 1024 | 1007 | 1106 | 1003 | | 1029 | |
| | 15 . | 1076 | 1072 | 1067 | 1162 | 1039 | 1023 | 1074 | 1072 |
| | 25 . | 1120 | 1127 | 1087 | 1220 | 1079 | | 1116 | |
| September | 5 . | 1172 | 1143 | 1137 | 1302 | 1126 | | 1163 | |
| | 15 . | 1200 | 1165 | 1165 | 1419 | 1162 | 1118 | 1206 | 1207 |
| | 25 . | 1230 | 1188 | 1197 | 1576 | 1184 | | 1251 | |
| October | 5 . | 1258 | 1188 | 1213 | 1691 | 1210 | | 1285 | |
| | 15 . | 1271 | 1204 | 1252 | 1728 | 1237 | 1168 | 1310 | 1267 |
| | 25 . | 1278 | 1210 | 1271 | 1691 | 1261 | | 1316 | |
| November | 5 . | 1281 | 1204 | 1288 | 1646 | 1268 | | 1312 | |
| | 15 . | 1288 | 1201 | 1295 | 1576 | 1268 | 1188 | 1302 | |
| | 25 . | 1288 | 1184 | 1295 | 1553 | 1274 | | 1296 | |
| December | 5 . | 1281 | 1140 | 1302 | 1534 | 1278 | | 1283 | |
| | 15 . | 1268 | 1045 | 1295 | 1534 | 1276 | 1044 | 1249 | |
| | 25 . | 1207 | 949 | 1281 | 1534 | 1274 | | 1198 | |
| Means | . | 937 | 902 | 885 | 1100 | 978 | 895 | 950 | |

TABLE 121.—DISCHARGES OF THE WHITE, BLUE, AND MAIN NILE AT KHARTOUM FOR 1911 (in cubic metres per second).

| Date. | White Nile. | Blue Nile. | Main Nile. | Date. | White Nile. | Blue Nile. | Main Nile. |
|---|---|---|---|---|---|---|---|
| Jan. 1– 5 | 1190 | 600 | 1790 | July 1– 5 | 680 | 820 | 1500 |
| 6–10 | 1210 | 560 | 1770 | 6–10 | 680 | 1080 | 1760 |
| 11–15 | 1220 | 510 | 1730 | 11–15 | 820 | 1360 | 2180 |
| 16–20 | 1220 | 480 | 1700 | 16–20 | 560 | 2040 | 2600 |
| 21–25 | 1230 | 430 | 1660 | 21–25 | 540 | 2380 | 2920 |
| 26–31 | 1240 | 390 | 1630 | 26–31 | 640 | 2760 | 3400 |
| Feb. 1– 5 | 1190 | 360 | 1550 | Aug. 1– 5 | 800 | 3500 | 4300 |
| 6–10 | 1150 | 330 | 1480 | 6–10 | 120 | 5000 | 5120 |
| 11–15 | 1060 | 310 | 1370 | 11–15 | – 560 | 6760 | 6200 |
| 16–20 | 960 | 290 | 1250 | 16–20 | – 110 | 7660 | 7550 |
| 21–25 | 850 | 270 | 1120 | 21–25 | 60 | 8440 | 8500 |
| 26–28 | 760 | 250 | 1010 | 26–31 | 440 | 8300 | 8740 |
| Mar. 1– 5 | 680 | 240 | 920 | Sept. 1– 5 | 550 | 8180 | 8730 |
| 6–10 | 640 | 230 | 870 | 6–10 | 190 | 8400 | 8590 |
| 11–15 | 610 | 220 | 830 | 11–15 | 140 | 8220 | 8360 |
| 16–20 | 620 | 200 | 820 | 16–20 | 420 | 7780 | 8200 |
| 21–25 | 590 | 200 | 790 | 21–25 | 580 | 6500 | 7080 |
| 26–31 | 580 | 180 | 760 | 26–30 | 800 | 5260 | 6060 |
| Apr. 1– 5 | 550 | 180 | 730 | Oct. 1– 5 | 1300 | 4200 | 5500 |
| 6–10 | 530 | 170 | 700 | 6–10 | 1560 | 3640 | 5200 |
| 11–15 | 520 | 160 | 680 | 11–15 | 1620 | 3300 | 4920 |
| 16–20 | 510 | 150 | 680 | 16–20 | 1600 | 2960 | 4560 |
| 21–25 | 520 | 140 | 660 | 21–25 | 1520 | 2680 | 4200 |
| 26–30 | 520 | 140 | 660 | 26–31 | 1400 | 2360 | 3760 |
| May 1– 5 | 510 | 160 | 670 | Nov. 1– 5 | 1260 | 2140 | 3400 |
| 6–10 | 520 | 180 | 700 | 6–10 | 1140 | 1940 | 3080 |
| 11–15 | 520 | 210 | 730 | 11–15 | 1020 | 1720 | 2740 |
| 16–20 | 530 | 230 | 760 | 16–20 | 960 | 1500 | 2460 |
| 21–25 | 550 | 230 | 780 | 21–25 | 1000 | 1280 | 2280 |
| 26–31 | 570 | 230 | 800 | 26–30 | 980 | 1200 | 2180 |
| June 1– 5 | 590 | 220 | 810 | Dec. 1– 5 | 1000 | 1100 | 2100 |
| 6–10 | 570 | 240 | 810 | 6–10 | 970 | 1040 | 2010 |
| 11–15 | 580 | 300 | 880 | 11–15 | 980 | 950 | 1930 |
| 16–20 | 630 | 410 | 1040 | 16–20 | 970 | 860 | 1830 |
| 21–25 | 660 | 540 | 1200 | 21–25 | 930 | 800 | 1730 |
| 26–30 | 680 | 660 | 1340 | 26–31 | 950 | 660 | 1610 |

TABLE 122.—DINDER RIVER DISCHARGE, 1911 (in cubic metres per second).

| Date. | | Gauge Readings. Five-day means. | Volume Discharged. | Monthly. |
|---|---|---|---|---|
| July | 1– 5 | 10·93 | 20 | 80 |
| | 6–10 | 11·25 | 32 | |
| | 11–15 | 11·99 | 79 | |
| | 16–20 | 11·62 | 53 | |
| | 21–25 | 11·55 | 49 | |
| | 26–31 | 13·73 | 227 | |
| August | 1– 5 | 14·13 | 282 | 400 |
| | 6–10 | 14·24 | 296 | |
| | 11–15 | 14·40 | 317 | |
| | 16–20 | 15·29 | 444 | |
| | 21–25 | 14·88 | 383 | |
| | 26–31 | 16·28 | 605 | |
| September | 1– 5 | 16·75 | 700 | 540 |
| | 6–10 | 16·89 | 725 | |
| | 11–15 | 15·57 | 667 | |
| | 16–20 | 16·00 | 565 | |
| | 21–25 | 14·75 | 365 | |
| | 26–30 | 13·67 | 220 | |
| October | 1– 5 | 13·15 | 165 | 160 |
| | 6–10 | 14·25 | 297 | |
| | 11–15 | 13·33 | 183 | |
| | 16–20 | 12·29 | 100 | |
| | 21–25 | 12·02 | 81 | |
| | 26–31 | 11·75 | 60 | |
| November | 1– 5 | 12·02 | 81 | 40 |
| | 6–10 | 11·63 | 54 | |
| | 11–15 | 11·34 | 37 | |
| | 16–20 | 11·16 | 28 | |
| | 21–25 | 10·99 | 22 | |
| | 26–30 | 10·69 | 14 | |
| December | 1– 5 | 10·51 | 10 | 10 |
| | 6–10 | 10·60 | 12 | |
| | 11–15 | 10·67 | 14 | |
| | 16–20 | 10·59 | 12 | |
| | 21–25 | 10·54 | 11 | |
| | 26–31 | 10·45 | 9 | |

Mean discharge for the year, 100 cubic metres per second. A year of very poor rainfall.

TABLE 123.—RAHAD RIVER DISCHARGE, 1911 (in cubic metres per second).

| Date. | | Volume Discharged. | Monthly. | Date. | | Volume Discharged. | Monthly. |
|---|---|---|---|---|---|---|---|
| July | 1–5 | ... | 20 | October | 1–5 | 206 | 110 |
| | 6–10 | ... | | | 6–10 | 187 | |
| | 11–15 | 7 | | | 11–15 | 135 | |
| | 16–20 | 11 | | | 16–20 | 87 | |
| | 21–25 | 27 | | | 21–25 | 55 | |
| | 26–31 | 85 | | | 26–31 | 29 | |
| August | 1–5 | 124 | 130 | November | 1–5 | 17 | 20 |
| | 6–10 | 123 | | | 6–10 | 25 | |
| | 11–15 | 116 | | | 11–15 | 34 | |
| | 16–20 | 122 | | | 16–20 | 19 | |
| | 21–25 | 134 | | | 21–25 | 8 | |
| | 26–31 | 148 | | | 26–30 | 3 | |
| September | 1–5 | 161 | 180 | | | | |
| | 6–10 | 172 | | | | | |
| | 11–15 | 178 | | | | | |
| | 16–20 | 179 | | | | | |
| | 21–25 | 188 | | | | | |
| | 26–30 | 203 | | | | | |

Mean discharge for the year, 40 cubic metres per second. A year of very poor rainfall.

TABLE 124.—APPROXIMATE DISCHARGES IN A MEAN YEAR AT KHARTOUM, OF THE ATBARA, AND AT WADI HALFA (in cubic metres per second).

| Month. | White Nile at Khartoum. | Blue Nile at Khartoum. | Main Nile at Khartoum. | The Atbara. | Main Nile at Wadi Halfa. |
|---|---|---|---|---|---|
| January . . . | 1200 | 500 | 1700 | 30 | 1650 |
| February . . | 1030 | 300 | 1330 | 10 | 1260 |
| March . . . | 630 | 200 | 830 | ... | 930 |
| April . . . | 540 | 100 | 640 | ... | 700 |
| May . . . | 560 | 200 | 760 | ... | 600 |
| June . . . | 640 | 500 | 1140 | 100 | 750 |
| July . . . | 670 | 2200 | 2870 | 500 | 2230 |
| August . . . | 150 | 6800 | 6950 | 1800 | 8000 |
| September . . | 450 | 7500 | 7950 | 1500 | 9050 |
| October . . . | 1650 | 3900 | 5550 | 300 | 6250 |
| November . . | 1170 | 1800 | 2970 | 100 | 3300 |
| December . . | 1080 | 1000 | 2080 | 50 | 2180 |
| Year . . | 800 | 2100 | 2900 | 360 | 3080 |

TABLE 125.—WADI HALFA DISCHARGES (in cubic metres per second).

| Date. | | 1892. | 1907. | 1908. | 1912. | Mean of 15 Years (1890-1904). |
|---|---|---|---|---|---|---|
| January | 1- 5 | 1910 | 1520 | 1290 | 1630 | 1800 |
| | 6-10 | 1770 | 1490 | 1280 | 1610 | 1710 |
| | 11-15 | 1710 | 1430 | 1210 | 1520 | 1680 |
| | 16-20 | 1610 | 1340 | 1150 | 1430 | 1660 |
| | 21-25 | 1600 | 1300 | 1090 | 1330 | 1590 |
| | 26-31 | 1520 | 1240 | 990 | 1240 | 1500 |
| | | 1690 | 1390 | 1170 | 1460 | 1650 |
| February | 1- 5 | 1410 | 1170 | 930 | 1160 | 1420 |
| | 6-10 | 1300 | 1090 | 880 | 1090 | 1360 |
| | 11-15 | 1190 | 1050 | 800 | 1020 | 1290 |
| | 16-20 | 1080 | 980 | 750 | 960 | 1240 |
| | 21-25 | 980 | 920 | 700 | 890 | 1160 |
| | 26-28 | 900 | 870 | 700 | 850 | 1110 |
| | | 1140 | 1010 | 790 | 960 | 1260 |
| March | 1- 5 | 830 | 820 | 680 | 800 | 1060 |
| | 6-10 | 790 | 750 | 670 | 730 | 1000 |
| | 11-15 | 720 | 700 | 640 | 700 | 950 |
| | 16-20 | 660 | 670 | 610 | 690 | 900 |
| | 21-25 | 640 | 660 | 600 | 670 | 860 |
| | 26-31 | 590 | 660 | 570 | 650 | 820 |
| | | 710 | 710 | 630 | 710 | 930 |
| April | 1- 5 | 540 | 660 | 530 | 620 | 780 |
| | 6-10 | 510 | 650 | 510 | 580 | 740 |
| | 11-15 | 480 | 650 | 500 | 560 | 710 |
| | 16-20 | 460 | 640 | 480 | 530 | 690 |
| | 21-25 | 440 | 620 | 480 | 530 | 660 |
| | 26-30 | 420 | 590 | 480 | 510 | 630 |
| | | 480 | 640 | 500 | 550 | 700 |
| May | 1- 5 | 410 | 590 | 470 | 500 | 610 |
| | 6-10 | 400 | 590 | 450 | 470 | 590 |
| | 11-15 | 390 | 660 | 440 | 460 | 600 |
| | 16-20 | 410 | 660 | 440 | 470 | 600 |
| | 21-25 | 380 | 670 | 440 | 450 | 590 |
| | 26-31 | 370 | 650 | 440 | 440 | 580 |
| | | 390 | 640 | 450 | 470 | 600 |
| June | 1- 5 | 380 | 640 | 480 | 420 | 590 |
| | 6-10 | 400 | 600 | 520 | 410 | 620 |
| | 11-15 | 400 | 560 | 520 | 430 | 660 |
| | 16-20 | 440 | 600 | 530 | 430 | 740 |
| | 21-25 | 540 | 650 | 500 | 440 | 870 |
| | 26-30 | 670 | 670 | 530 | 470 | 990 |
| | | 470 | 620 | 510 | 430 | 750 |

TABLE 125.—WADI HALFA DISCHARGES (*continued*).

| Date. | | 1892. | 1907. | 1908. | 1912. | Mean of 15 Years (1890-1904). |
|---|---|---|---|---|---|---|
| July | 1-5 | 770 | 780 | 570 | 540 | 1130 |
| | 6-10 | 1,220 | 910 | 740 | 750 | 1320 |
| | 11-15 | 1,490 | 1010 | 1,100 | 1120 | 1610 |
| | 16-20 | 2,290 | 1120 | 1,290 | 1560 | 2290 |
| | 21-25 | 3,500 | 1830 | 1,780 | 1890 | 2990 |
| | 26-31 | 5,290 | 2580 | 2,870 | 2460 | 3990 |
| | | 2,450 | 1380 | 1,400 | 1400 | 2230 |
| August | 1-5 | 7,220 | 3760 | 3,660 | 5110 | 5410 |
| | 6-10 | 7,990 | 3560 | 5,040 | 6490 | 7010 |
| | 11-15 | 8,070 | 3960 | 8,530 | 7390 | 7930 |
| | 16-20 | 8,930 | 4900 | 10,130 | 8410 | 8660 |
| | 21-25 | 11,060 | 6020 | 10,720 | 8150 | 9120 |
| | 26-31 | 11,210 | 6670 | 9,830 | 8390 | 9360 |
| | | 9,080 | 4810 | 7,980 | 7320 | 8000 |
| September | 1-5 | 11,490 | 7750 | 9,860 | 8350 | 9450 |
| | 6-10 | 11,870 | 7030 | 10,820 | 8450 | 9380 |
| | 11-15 | 11,740 | 6930 | 10,340 | 7580 | 9340 |
| | 16-20 | 11,710 | 6950 | 9,950 | 7050 | 9340 |
| | 21-25 | 11,710 | 6890 | 9,650 | 6540 | 8700 |
| | 26-30 | 10,950 | 6400 | 9,100 | 6450 | 8190 |
| | | 11,580 | 6990 | 9,960 | 7400 | 9050 |
| October | 1-5 | 10,360 | 5690 | 8,640 | 5840 | 7650 |
| | 6-10 | 9,470 | 4920 | 8,470 | 5020 | 7160 |
| | 11-15 | 8,830 | 4080 | 8,230 | 4240 | 6570 |
| | 16-20 | 8,210 | 3430 | 7,250 | 3580 | 6000 |
| | 21-25 | 7,540 | 3140 | 6,230 | 3090 | 5380 |
| | 26-31 | 6,680 | 2930 | 5,520 | 2660 | 4750 |
| | | 8,520 | 4030 | 7,390 | 4070 | 6250 |
| November | 1-5 | 5,680 | 2680 | 4,390 | 2360 | 4190 |
| | 6-10 | 4,800 | 2500 | 3,900 | 2250 | 3680 |
| | 11-15 | 4,340 | 2310 | 3,220 | 2110 | 3320 |
| | 16-20 | 3,920 | 2080 | 2,910 | 2030 | 3070 |
| | 21-25 | 3,580 | 1860 | 2,670 | 1900 | 2890 |
| | 26-30 | 3,290 | 1770 | 2,390 | 1770 | 2590 |
| | | 4,270 | 2200 | 3,250 | 2070 | 3300 |
| December | 1-5 | 3,150 | 1670 | 2,270 | 1700 | 2490 |
| | 6-10 | 2,970 | 1640 | 2,100 | 1630 | 2350 |
| | 11-15 | 2,910 | 1550 | 1,970 | 1550 | 2240 |
| | 16-20 | 2,730 | 1530 | 1,870 | ... | 2120 |
| | 21-25 | 2,690 | 1440 | 1,800 | ... | 2000 |
| | 26-31 | 2,620 | 1390 | 1,710 | ... | 1890 |
| | | 2,820 | 1540 | 1,950 | | 2180 |
| Year | | 3,630 | 2160 | 3,000 | 2370 | 3080 |

The following table gives the contents of the Aswan Reservoir :—

Table 126.—Contents of the Aswan Reservoir.

| Metres. | Cubic Metres. | Metres. | Cubic Metres. |
|---|---|---|---|
| R.L. 93·00 | | R.L. 105·00 | 825,000,000 |
| 94·00 | 24,000,000 | 106·00 | 975,000,000 |
| 95·00 | 40,000,000 | 107·00 | 1,125,000,000 |
| 96·00 | 75,000,000 | 108·00 | 1,310,000,000 |
| 97·00 | 110,000,000 | 109·00 | 1,500,000,000 |
| 98·00 | 165,000,000 | 110·00 | 1,700,000,000 |
| 99·00 | 225,000,000 | 111·00 | 1,925,000,000 |
| 100·00 | 300,000,000 | 112·00 | 2,150,000,000 |
| 101·00 | 380,000,000 | 113·00 | 2,425,000,000 |
| 102·00 | 475,000,000 | If raised { 115·00 | 3,000,000,000* |
| 103·00 | 580,000,000 | If raised { 118·00 | 4,000,000,000* |
| 104·00 | 690,000,000 | | |

* The contents of the reservoir at reduced levels 115 and 118 were 2,800,000,000 and 3,700,000,000 cubic metres in the 1894 Report; but according to the more recent calculations of the P.W. Ministry for R.L. 113, these figures need to be increased, and we have consequently made them as above (for it is impossible for the reservoir to impound less between R.L. 113 and 115 than between R.L. 111 and 113).

We now give a few tables of general interest :—

Table 127 gives the mean monthly discharges at Khartoum, Aswan, and Cairo for the maximum, minimum, and mean years.

Table 128 gives the reduced levels of mean low water on the Nile. At Aswan the mean low water is R.L. 85,000.

Table 129 gives the areas and cross sections of the Nile from Aswan to Cairo.

Table 130 gives the cubic contents of the trough of the Nile from Aswan to Cairo.

Table 131 gives width of water surface of the Nile from Aswan to Cairo.

These tables are useful for calculating the water lost in filling the trough of the Nile on a rising gauge, the water given back on a falling gauge, and the loss by evaporation. They have nothing to do with the water given back by seepage on a falling gauge.

TABLE 127.—TABLE OF MEAN MONTHLY DISCHARGES AT KHARTOUM, ASWAN, AND CAIRO, FOR THE MAXIMUM, MINIMUM, AND MEAN YEARS.

(Cubic metres per second.)

| Month. | 1877–78. Minimum Year. | | | 1878–79. Maximum Year. | | | Mean of 20 Years. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Blue Nile at Khartoum. | Aswan. | Cairo. | Blue Nile at Khartoum. | Aswan. | Cairo. | Blue Nile at Khartoum. | Aswan. | Cairo. |
| June | 1000 | 800 | 600 | 1,000 | 500 | 250 | 1000 | 750 | 500 |
| July | 2800 | 2400 | 1100 | 3,500 | 2,000 | 900 | 2800 | 2200 | 1100 |
| August | 5300 | 5600 | 3900 | 8,200 | 7,900 | 5,200 | 7000 | 7900 | 5300 |
| September | 4700 | 5900 | 4400 | 12,500 | 12,100 | 8,600 | 8500 | 9200 | 7200 |
| October | 2500 | 4000 | 3900 | 8,000 | 9,300 | 10,300 | 4500 | 6000 | 6900 |
| November | ... | 2400 | 2550 | ... | 4,700 | 6,500 | ... | 3300 | 3700 |
| December | ... | 1500 | 1600 | ... | 3,200 | 3,600 | ... | 2200 | 2300 |
| January | ... | 1200 | 1300 | ... | 2,400 | 2,600 | ... | 1600 | 1600 |
| February | ... | 800 | 800 | ... | 2,100 | 2,100 | ... | 1200 | 1200 |
| March | ... | 600 | 550 | ... | 1,900 | 1,900 | ... | 850 | 800 |
| April | ... | 500 | 400 | ... | 1,600 | 1,600 | ... | 700 | 620 |
| May | ... | 400 | 300 | ... | 1,500 | 1,500 | ... | 600 | 520 |
| Mean | ... | 2175 | 1783 | ... | 4,100 | 3,754 | ... | 3041 | 2645 |

Note the very high discharges at Aswan and Cairo in April and May 1879. The minimum discharge of that year was about 1500 cubic metres per second. There has never been any discharge like that since.

TABLE 128.—MEAN LOW WATER LEVEL OF THE NILE—ASWAN TO CAIRO.

| Distance from Aswan along Centre of Flood, in kilometres. | Name of Locality. | R.L. according to Reservoir Levels, metres. | R.L. according to Inspectors of Irrigation, metres. | Distance from Aswan along Summer Channel, in kilometres. |
|---|---|---|---|---|
| 0 | Aswan | 85·0 | 85·0 | 0 |
| 70 | Gebel Silsila | 79·3 | 79·4 | 72 |
| 106 | Edfu | 76·7 | 77·0 | |
| 157 | Esna | 73·1 | 72·6 | |
| 194 | Armant | 70·1 | 69·6 | |
| 213 | Luxor | 69·0 | 68·5 | |
| 272 | Kena | 65·3 | 64·8 | |
| 320 | Kasr-es-Saad | 61·7 | 61·2 | 330 |
| 328 | Heu | 61·2 | 60·7 | |
| 333 | Naga Hammadi | 61·0 | 60·5 | |
| 365 | Abu Shusha | 58·6 | 58·1 | |
| 373 | Balyana | 58·3 | 57·8 | |
| 390 | Girga | 56·9 | 56·5 | |
| 429 | Sohag | 53·8 | 53·2 | |
| 470 | Khazindaria | 49·9 | 49·4 | 489 |
| 505 | Abutig Escape | 47·7 | 47·1 | |
| 530 | Assiut * | 45·55 | 45·05 | 552 |
| 598 | Derut Escape | 39·1 | 38·5 | |
| 627 | Roda | 36·3 | 35·7 | |
| 666 | Minia | 32·6 | 32·0 | |
| 710 | Beni Mazâr | 28·9 | ... | 748 |
| 783 | Beni Suef (†) | 22 1 | 21·8 | |
| 800 | Ashmant | 20·5 | 20·2 | 842 |
| 817 | Koshesha Escape | 18·9 | 18·6 | |
| ... | El-Ayât | 15·8 | 15·5 | |
| 898 | Cairo gauge | 12·10 | 12·25 | |
| 900 | Cairo | 12·00 | 12·1 | 948 |

These levels are independent of the water added by the Aswan Reservoir.

* Downstream of the Assiut weir.

† The Beni Suef gauge is unreliable in summer as it is on a branch of the river which is dammed by the villagers.

TABLE 129.—TABLE GIVING AREAS OF CROSS SECTIONS OF THE NILE, FROM ASWAN TO CAIRO.

| Locality. | Length in kilo-metres. | Mean Area in Square Metres | | | | | |
|---|---|---|---|---|---|---|---|
| | | Below Mean Low Water Level. | Below 6 metres.* | Below 7 metres. | Below 8 metres. | Below 8·5 metres. | Below 9 metres. |
| Aswan to Ramadi . . | 81 | 1024 | 4930 | 5808 | 6754 | 7337 | 7,993 |
| Ramadi to Esna . . | 76 | 674 | 4554 | 5461 | 6398 | 6966 | 7,695 |
| Esna to Kena . . . | 115 | 852 | 4476 | 5536 | 6221 | 6726 | 7,363 |
| Kena to Sohag . . | 158 | 973 | 4718 | 5600 | 6535 | 7121 | 7,873 |
| Sohag to Assiut . . | 98 | 1037 | 5220 | 6305 | 7705 | 8683 | 9,749 |
| Assiut to Minia . . | 138 | 899 | 5149 | 6205 | 7783 | 8845 | 9,937 |
| Minia to Beni Suef . . | 117 | 915 | 5035 | 6007 | 7315 | 8196 | 9,140 |
| Beni Suef to Koshesha . | 34 | 665 | 5040 | 6080 | 7532 | 8379 | 9,247 |
| Koshesha to Cairo . . | 81 | 1031 | 5364 | 6388 | 7813 | 8648 | 9,495 |
| Cairo to the Barrage . | 24 | 1402 | 5414 | 6628 | 8346 | 9258 | 10,184 |
| Aswan to Assiut . . | 528 | 920 | 4760 | 5680 | 6690 | 7310 | 8,080 |
| Assiut to Koshesha . . | 289 | 870 | 5080 | 6100 | 7550 | 8510 | 9,520 |
| Koshesha to Cairo . . | 81 | 1030 | 5360 | 6380 | 7810 | 8640 | 9,490 |
| Aswan to Cairo . . | 898 | 910 | 4930 | 5890 | 7080 | 7830 | 8,690 |

* Metres are referred to mean low water.

TABLE 130.—TABLE OF THE CUBIC CONTENTS OF THE TROUGH OF THE NILE FROM ASWAN TO CAIRO.

| Locality. | Length in Kilometres. | Contents in Millions of Cubic Metres. | | | | | | Contents in Millions of Cubic Metres. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Below Mean Low Water-Level. | From Zero to 6·0.* | From 6·0 to 7·0. | From 7·0 to 8·0. | From 8·0 to 8·5. | From 8·5 to 9·0. | Below Zero. | Below 6·0. | Below 7·0. | Below 8·0. | Below 8·5. | Below 9·0. |
| Aswan to Ramadi . | 81 | 83 | 316 | 71 | 77 | 47 | 53 | 83 | 399 | 470 | 547 | 594 | 647 |
| Ramadi to Esna . | 76 | 51 | 295 | 69 | 71 | 43 | 56 | 51 | 346 | 415 | 486 | 529 | 585 |
| Esna to Kena . . | 115 | 98 | 417 | 99 | 102 | 58 | 73 | 98 | 514 | 614 | 715 | 773 | 847 |
| Kena to Sohag . | 128 | 154 | 592 | 139 | 148 | 83 | 119 | 154 | 745 | 885 | 1032 | 1125 | 1244 |
| Sohag to Assiut . | 98 | 102 | 410 | 106 | 137 | 96 | 104 | 102 | 512 | 618 | 755 | 851 | 955 |
| Assiut to Minia . | 138 | 124 | 586 | 146 | 218 | 147 | 151 | 124 | 710 | 856 | 1074 | 1220 | 1371 |
| Minia to Beni Suef . | 117 | 107 | 482 | 114 | 153 | 103 | 110 | 107 | 589 | 703 | 856 | 859 | 1069 |
| Beni Suef to Koshesha | 34 | 23 | 149 | 35 | 49 | 29 | 29 | 23 | 171 | 207 | 256 | 285 | 314 |
| Koshesha to Cairo . | 81 | 84 | 351 | 83 | 115 | 68 | 69 | 84 | 434 | 517 | 633 | 700 | 769 |
| Cairo to the Barrage . | 28 | 34 | 96 | 29 | 41 | 22 | 22 | 34 | 130 | 159 | 200 | 222 | 244 |
| Aswan to Assiut . | 528 | 487 | 2030 | 484 | 534 | 327 | 405 | 487 | 2517 | 3001 | 3535 | 3862 | 4267 |
| Assiut to Koshesha . | 289 | 254 | 1217 | 295 | 420 | 278 | 291 | 254 | 1471 | 1766 | 2186 | 2464 | 2755 |
| Koshesha to Cairo . | 81 | 84 | 351 | 83 | 115 | 68 | 69 | 84 | 435 | 518 | 633 | 701 | 770 |
| Aswan to Cairo . | 898 | 825 | 3598 | 862 | 1069 | 673 | 765 | 825 | 4423 | 5285 | 6354 | 7027 | 7792 |

* Zero is mean low water, and the metres are referred to mean low water.

TABLE 131.—WIDTHS OF WATER SURFACE FROM ASWAN TO CAIRO.

| From | To | Distance in kilometres. | Mean Width of Water Surface in Metres. | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0* | 6·0* | 7·0 | 8·0 | 8·5 | 9·0 |
| Aswan . | Ramadi . | 81 | 400 | 840 | 880 | 1030 | 1270 | 1400 |
| Ramadi . | Esna . | 76 | 340 | 850 | 890 | 1030 | 1260 | 1620 |
| Esna . . | Kena . | 115 | 350 | 820 | 850 | 940 | 1120 | 1400 |
| Kena . . | Sohag . | 158 | 380 | 870 | 890 | 1000 | 1300 | 1560 |
| Sohag . | Assiut . | 98 | 400 | 1000 | 1170 | 1720 | 2080 | 2170 |
| Assiut . | Minia . | 138 | 390 | 970 | 1180 | 1890 | 2060 | 2080 |
| Minia . | Beni Suef . | 117 | 490 | 960 | 1300 | 1550 | 1800 | 1840 |
| Beni Suef . | Koshesha . | 34 | 500 | 1000 | 1390 | 1690 | 1720 | 1730 |
| Koshesha . | Cairo . | 81 | 450 | 960 | 1100 | 1570 | 1700 | 1700 |
| Cairo . . | Barrage . | 24 | 440 | 940 | 1460 | 1840 | 1860 | 1890 |
| Aswan . | Assiut . | 528 | 370 | 880 | 940 | 1140 | 1410 | 1630 |
| Assiut . | Cairo . . | 370 | 460 | 980 | 1250 | 1700 | 1830 | 1840 |
| Aswan . | Cairo . . | 898 | 410 | 920 | 1070 | 1370 | 1580 | 1728 |

AREA OF WATER SURFACE IN MILLIONS OF SQUARE METRES.

| From | To | Distance | 0* | 6·0* | 7·0 | 8·0 | 8·5 | 9·0 |
|---|---|---|---|---|---|---|---|---|
| Aswan . | Assiut . | 528 | 195 | 465 | 500 | 605 | 745 | 865 |
| Assiut . | Cairo . . | 370 | 170 | 360 | 460 | 630 | 675 | 680 |
| Aswan . | Cairo . . | 898 | 365 | 825 | 960 | 1235 | 1420 | 1545 |

* Zero is mean low water. 6·0 is 6 metres above mean low water. See Table 128.

28. **General Information about the Nile and its Utilisation in Egypt.**—The moduli of the Nile and its tributaries are tabulated here for convenience. Some of the mean discharges for the year, or moduli, are approximate, but they embody all the information at our disposal to-day.

| | Cubic metres per second. |
|---|---|
| Victoria Nile at the Ripon Falls . . . . | 610 |
| Albert Nile at Wadelai . . . . . | 790 |
| „ „ Mongalla . . . . | 1070 |
| „ „ above the Sobat Junction . . . | 490 |
| Sobat River at its tail . . . . . | 470 |
| Gazelle River . . . . . . | 20 |
| White Nile at Malakal . . . . . | 940 |
| „ „ Khartoum . . . . | 800 |
| Blue Nile at „ . . . . | 2100 |
| Main Nile at „ . . . . | 2900 |
| Atbara . . . . . . . | 360 |
| Main Nile at Wadi Halfa . . . . | 3080 |
| The tails of the Rosetta and Damietta Branches . | 2050 |

In 1897, when the second edition of this work was written, the discharge received by the 1,440,000 acres of basins in a mean year was 125 cubic metres per acre per day for forty days per annum, or a discharge of 2100 cubic metres per second for forty days. Good independent basins, like those of Girga, received 170 cubic metres per acre per day; and poor ones, like those on the Yusufi, interfered with by perennial irrigation, received only 90. To-day there are 1,000,000 acres under basin, but, owing to the numerous barrages on the Nile and the Yusufi, there are now practically no weak basins, and all may be said to be receiving 170 cubic metres per acre per day. The amount of water taken from the Nile in flood is thus 2000 cubic metres per second for the basins. The 300,000 acres of islands and berms receive 30 cubic metres per acre per day over half their area, or 50 cubic metres per second. The 1,300,000 acres of land classed as basin land receive therefore 2050 cubic metres per second.

The 1,000,000 acres of perennially irrigated land in Upper Egypt receive in flood 30 cubic metres per acre per day, or 350 cubic metres per second. Upper Egypt in flood takes therefore 2400 cubic metres per second.

Lower Egypt in flood utilises for its 3,100,000 acres of perennial land a mean discharge of 27 cubic metres per acre per day, or 970 cubic metres per second.

Egypt therefore takes in flood 3400 cubic metres per second.

In winter the basins take nothing, but one-third of the islands and berms are irrigated with 16 cubic metres per acre per day, or 20 cubic metres per second. The perennial area of Upper Egypt of 1,000,000 acres utilises in winter 14 cubic metres per acre a day, or 160 cubic metres per second.

Upper Egypt in winter utilises therefore 180 cubic metres per second.

In winter Lower Egypt utilises 12 cubic metres per acre per day, or 430 cubic metres per second.

Egypt therefore in winter utilises 610 cubic metres per second.

In summer Upper Egypt takes 180 cubic metres per second, and Lower Egypt 570—or 750 for the whole of Egypt.

The flood, winter, and summer discharges of Egypt are therefore 3400, 610, and 750 cubic metres per second respectively.

Now, the basin tracts are irrigated for forty days with 2000 cubic metres per second, half of which is discharged back into the Nile. The water utilised, spread over the year, means $\frac{1}{2} \times \frac{40 \times 2000}{365}$, or 110 cubic metres per second.

The islands and berms take in flood 50 cubic metres per second for ninety days: in winter 20 cubic metres per second for ninety days, and in

summer 20 cubic metres per second for a hundred days. This, spread over the year, means $\frac{(50 \times 90)+(20 \times 90)+(20 \times 100)}{365}$, or 23 cubic metres per second.

The perennially irrigated lands in Upper and Lower Egypt take (350+970, or) 1320 cubic metres per second in flood for ninety days; (160+430, or) 590 cubic metres in winter for ninety days; and in summer (160+570, or) 750 cubic metres per second for 120 days. This, spread over the year, means $\frac{(1320 \times 90)+(590 \times 90)+(750 \times 120)}{365}$, or 700 cubic metres per second.

Egypt therefore takes in the year (110+20+700, or) 830 cubic metres per second for the irrigation of its 5,400,000 acres of cultivated land.

The basin lands cover 1,000,000 acres, and a discharge of 110 cubic metres per second for a year means a mean depth of water over the land of $\frac{3,500,000,000}{4,200,000,000}$ or ·83 metre: equivalent to a monsoon rainfall of 33 inches.

The islands and berms cover 300,000 acres, and 23 cubic metres per second discharged for a year means a mean depth of water of $\frac{730,000,000}{1,260,000,000}$, or ·58 metre, or 22 inches.

The perennially irrigated area covers 4,000,000 acres, and 700 cubic metres per second discharged for a year means a mean depth of $\frac{22,000,000,000}{17,000,000,000}$, or 1·30 metres, or a rainfall of 51 inches.

The mean depth of water distributed over the whole of Egypt is $\frac{26,270,000,000}{22,700,000,000}$, or 1·16 metres, equivalent to 46 inches per annum.

We have in addition the water which percolates into the soil from the river in flood, and returns in part to the river.

We now turn to the discharges entering Egypt and flowing into the sea; the difference between the two is that absorbed by the soil through irrigation or percolation and that evaporated. The mean discharge entering Egypt is 3080 cubic metres per second, and the mean discharge flowing into the Mediterranean by the branches is 2050 cubic metres per second. The balance is 1030 cubic metres per second. We have seen that 840 cubic metres per second is taken for irrigation, leaving 200 cubic metres per second as the quantity evaporated, as that percolating into the soil in excess of what returns, and the discharges of the canals into the lakes.

We now compare the quantity of solid matter carried by the Nile, the quantity deposited on the land, and the quantity taken to the sea. The following table gives in the second column, the mean silt content of Nile

water, in grams per cubic metre, averaged from six series of examinations of the silt.

TABLE 132.—SOLID MATTER IN THE NILE.

| Month. | Silt Content. Grams per Cubic Metre. | Discharge entering Egypt in a Mean Year. Cubic metres per second. | Silt Discharge of River at Aswan. Kilograms per second. | Discharge of the Rosetta and Damietta Branches into the Sea. Cubic metres per second. | Silt Discharge into the Sea. Kilograms per second. | Balance of Discharge spread on the Land. Cubic metres per second. | Silt Discharge on to the Land. Kilograms per second. |
|---|---|---|---|---|---|---|---|
| January . | 250 | 1650 | 410 | 1290 | 320 | 360 | 90 |
| February . | 175 | 1260 | 220 | 820 | 140 | 440 | 80 |
| March . | 100 | 930 | 90 | 500 | 50 | 430 | 40 |
| April . | 85 | 700 | 60 | 250 | 20 | 450 | 40 |
| May . | 70 | 600 | 40 | 80 | ... | 520 | 40 |
| June . | 100 | 750 | 70 | 0 | ... | 750 | 70 |
| July . | 150 | 2230 | 330 | 510 | 80 | 1720 | 250 |
| August . | 1430 | 8000 | 11,440 | 4280 | 6120 | 3720 | 5320 |
| September | 1320 | 9050 | 11,950 | 6000 | 7920 | 3050 | 4030 |
| October . | 830 | 6250 | 5,190 | 5660 | 4700 | 590 | 490 |
| November | 570 | 3300 | 1,880 | 3240 | 1850 | 60 | 30 |
| December | 360 | 2180 | 790 | 1960 | 710 | 220 | 80 |
| Year . | ... | 3080 | 2,710 | 2050 | 1830 | 1030 | 880 |

From these figures we deduce that:—

| | |
|---|---|
| The river carries . . . . | . 85,400,000 tons of solid matter. |
| The river discharges into the sea | . 57,600,000 " " |
| There is spread over the land . | . 27,800,000 " " |

Now we know that basin land receives 170 cubic metres per acre for forty days per annum, or 6800 cubic metres over 4200 square metres, or 1·60 metres in depth of water, between 20th August and 30th September, when the silt content is 1350 grams per cubic metre. This means 2200 grams per square metre per annum, or 220,000 grams per square metre per hundred years. As the specific gravity of Nile silt is 2·2, this means ·100 cubic metre per hundred years per square metre, or 10 centimetres in depth of deposit every hundred years.

We know, moreover, that the Nile in high flood scours out its bed, and in a low flood silts it up, and it is owing to the fact that low floods are more numerous than high ones that the silting process gains on the scouring and there is a rise of about 12 centimetres per hundred years as calculated from the gauges. The Nile berms and islands rise with the Nile as they get all the heavy silt, and their rate is the same as that of the Nile, or 12 centimetres, while the basins rise about 10 centimetres per hundred years. As each acre of the basin tracts of

1,300,000 acres receives 2200 × 4200 grams, or 9·3 tons, of deposit per annum, the whole area receives 12,000,000 tons per annum. As the whole of Egypt receives 27,800,000 tons, there remains for the whole of the perennially irrigated land, the waste land, and the lakes covering 6,700,000 acres, only 15,800,000 tons, or 2¼ tons per acre, or under one-quarter of the deposit received by the basin lands.

The barrages on the Nile have made Upper and Lower Egypt more or less independent of a low Nile; but we record here, as a matter of history, the state of the irrigation of the country before the barrages were constructed.

With a maximum gauge at Aswan of R.L. 91·50 metres there was famine.<br>
" " " between 91·50 and 92·25 metres, difficult irrigation.<br>
" " " " 92·25 and 92·75 metres, a little difficulty.<br>
" " " " 92·75 and 93·25 metres, perfect irrigation.<br>
" " " " 93·25 and 93·75 metres, floods.<br>
" " " above 93·75 metres, inundation and harm.

Egypt to-day is in no way protected against a very high flood like that of 1878.

## CHAPTER III.

# *THE NILE IN DETAIL.*

29. Lake Victoria Nyanza. — 30. The Victoria Nile. — 31 Lake Albert Nyanza. — 32. The Albert Nile.—33. The Zeraf River.—34. The Gazelle River.—35. The Sobat River.—36. The Sudd Region.—37. The White Nile.—38. The Blue Nile.—39. The Atbara.—40. The Nile from Khartoum to Aswan.—41. The Nile from Aswan to the Delta Barrage.—42. The Rosetta and Damietta Branches.

29. **Lake Victoria Nyanza.**—Lake Victoria, the true source of the Nile, lies on the equator, and, fed by abundant rains and numerous streams, discharges its surplus waters over the Ripon Falls, and gives birth to the Victoria Nile.

The watershed of the basin draining into the lake lies close to it on its north and south, and the chief feeders lie on the east and west sides. The catchment area is 246,000 square kilometres, of which 67,000 square kilometres are occupied by the surface of the lake itself, whose greatest length is 400 kilometres and greatest breadth 320 kilometres, with a coast line of over 3200 kilometres. Traces of old shore lines in the Kavirondo Gulf, on the islands in the north, and in the valley of the Kagera, bear witness that the lake was once more extensive and its level higher than is now the case, but even now it is the largest fresh-water lake in the old world. Its waters are beautifully clear and perfectly sweet. The depth of the lake is not great, and it is covered with many islands. The greatest known depth is 82 metres, while the bays are so shallow that a fall of the water-level of a metre seriously inconveniences navigation.

The northern, eastern, and southern shores of the lake, as described by Sir William Garstin, are generally clear, while the western shore, especially at the mouth of the Kagera, is flat, marshy, and covered with papyrus.

The country surrounding the lake is undulating or hilly, and rises to a height of 700 metres above it at the south-east corner. The rocks are generally gneiss, quartz, and schists. Marls and red clays cover the higher parts, and the valleys consist of black loam.

The Kagera, its principal feeder, rises in latitude 2°·5 S., near Lake Kivu, and drains the greater part of the country between Lake Victoria and the western chain of lakes. It is interesting as presenting in miniature the characteristics of the Nile itself. Reaches of slight slope, in which

the river meanders in papyrus-lined curves that must strongly resemble those of the Albert Nile in the marsh region, alternate with rapids down which it plunges. Where the slope is feeble, silting is in progress; where there are rapids, erosion is going on, and in the last part of its course the river has scoured out a bed in its own alluvium as it has accommodated itself to the fall in level of Lake Victoria. Finally, it discharges itself into the lake through a delta of its own formation. For the last 110 kilometres from the Mihingame Rapids it is navigable for a launch or small steamer.

Colonel Delmé-Radcliffe,* who surveyed much of this region in 1902, gives a description of the lower course. The valley of the Kagera is alluvial throughout, and is crossed at a few points by ridges of rocks, which give rise to the rapids and falls. No trace of volcanic rock was actually found, but hot springs were noticed. The valley offers facilities for the construction of a railway, and Colonel Delmé-Radcliffe considers that the line of this valley would be the easiest for the Cape to Cairo trunk railway to follow. The line would then continue through Buddu to Entebbe, which is destined one day to be the terminus of the present misnamed Uganda Railway.

Lake Victoria is fed by many rivers: three on the north, five on the east, two on the south, and four on the west. One of these last is the Kagera, with a maximum length of 825 kilometres and a discharge varying between 140 and some 600 cubic metres per second.

The north-eastern and western feeders are generally perennial streams, while many of the southern and eastern are torrents.

The triple rainy season prevails here. The principal maximum is in April, and the weakest of the three is in August on the south-east, south, and south-west; but in British East Africa and Uganda the weakest occurs in November and December.

The rainfall of the greatest rainy season is about four times that of the least, and the annual variation of the lake level shows the effect in a marked degree.

TABLE 133.—REGIMEN OF LAKE VICTORIA NYANZA.

| Month. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean level, 1896–1911 (metres) | ·612 | ·591 | ·609 | ·700 | ·811 | ·805 | ·726 | ·640 | ·593 | ·539 | ·530 | ·554 | ·642 |
| Mean discharge, 1902–1911, at Ripon Falls (cubic metres per sec.) | 589 | 578 | 587 | 624 | 670 | 669 | 647 | 620 | 601 | 587 | 580 | 590 | 612 |
| Mean rainfall on plateau (mm.) | 67 | 76 | 146 | 241 | 173 | 82 | 67 | 107 | 96 | 106 | 135 | 113 | 1409 |

* *Geog. Jour.*, 1905, pp. 481 and 616.

The lake rises in general from November to January after the autumn rains, falls slightly in February, and rises again to its main maximum in May, to fall at a steady rate until November again. The mean annual variation of the levels is only 28 centimetres, but the surface rises and falls by much greater amounts than this, consequent on variations in the intensity of the rain and evaporation, from one year to another.

It is interesting to make out a balance-sheet for the water supply of the lake. Let V and V′ be the volumes in the lake at two given dates (which in what follows we shall take to be one month apart), $x$ and $x'$ the gauge-readings at these dates, $f$ the mean rainfall over the basin (excluding the lake itself), $\rho$ the run-off, and $\sigma$ a fraction giving the ratio of the mean rainfall on the lake to that on the rest of the basin, A the water surface (which may be considered constant). The water entering the lake by the tributaries (Q) (including infiltration) and by direct rainfall (R) serves to supply that lost by discharge at the falls ($q$), by evaporation from the surface (E), and by seepage (which is practically nil), and to raise the level. Hence we may write—

$$\mathrm{Q}+\mathrm{R}=q+\mathrm{E}+\mathrm{V}'-\mathrm{V}.$$

But if A is the area of the lake, that of the basins of the tributaries is 2·7A from the data above. Hence $\mathrm{Q}=2{\cdot}7f\rho\mathrm{A}$, and $\mathrm{R}=\sigma f\mathrm{A}$. $q$ will depend on the gauge-readings during the interval under examination, but for practical purposes at Jinja may be put at $a'+b'\bar{x}$, where $\bar{x}$ is the mean gauge-reading during the interval. It is convenient to put this into the form $(a+b\bar{x})\mathrm{A}$, where now $a$ and $b$ do not give the volumes, but their equivalents in metres over the lake surface. As regards evaporation, data are too scanty. The chief factor is undoubtedly wind velocity, reliable observations of which are altogether wanting. It is safest, and probably not far from the truth, to assume a constant rate of evaporation ($e$) over the surface. The total evaporation will therefore be $e\mathrm{A}$. The change in volume is $\mathrm{A}(x'-x)$. Hence the equation becomes

$$2{\cdot}7\mathrm{A}\rho f+\mathrm{A}\sigma f=(a+b\bar{x})\mathrm{A}+e\mathrm{A}+(x'-x)\mathrm{A},$$

or, on division by A,

$$(2{\cdot}7\rho+\sigma)f=a+b\bar{x}+e+x'-x.$$

If we write $c=a+e$ and $k$ for $2{\cdot}7\rho+\sigma$, this becomes

$$x'-x=kf-(c+b\bar{x}).$$

As an approximate value of $\bar{x}$ we might write $\frac{1}{2}(x+x')$, when we should have an equation connecting $x'$, $x$, and $f$, and constants $k$, $b$, and $c$; and with enough values of the variables, we could determine the best values of the constants. But the discharge at Jinja for the past sixteen years has lain between 390 and 900 cubic metres per second, and the extreme variation from the mean

is only 255 cubic metres per second, which represents a layer of less than 10 millimetres from the surface per month, against an average monthly loss by evaporation amounting to something of the order of 100 to 120 millimetres. Thus in a first approximation, which is all that this pretends to be, we may neglect the variation of the discharge, and make the equation

$$x' - x = kf - c,$$

where $c$ is now a constant for the mean evaporation and discharge combined. It is worth while noting that this is more nearly constant than either separately, for evaporation is at its lowest during the rainy season when the gauge (and the discharge) is highest, and as the discharge falls the evaporation rises.

This equation has been examined by finding the coefficient of correlation between the change from the five-day mean gauge at the beginning of one month to that of the next and the rainfall in the first month, *i.e.* the average rainfall during the change. The monthly means for 1905 to 1910 have been used, and the coefficient is found to be $+0{\cdot}681$, which is high for work of this kind, but still, not being nearly unity, shows that we have not succeeded in explaining all the facts. It was considered that part of the rise might be due to the rainfall of the previous month. Calculation, however, shows that the correlation between the rise of the surface and this earlier rainfall is zero, and it follows that all the rain falling on the basin evaporates or finds its way into the lake within a month, or later as a constant discharge. The chief causes of the discrepancies are to be found in the variability of the coefficient of run-off, here assumed to be constant, and in the scarcity of rainfall observations.

The equation is found to be

$$x' - x = 1{\cdot}015(f - 0{\cdot}130).$$

This result is interesting. It shows that if the mean rainfall in a month does not exceed 0·130 metre, the level will fall. Again, it shows that the combined evaporation and discharge amount to $1{\cdot}015 \times 0{\cdot}130$, or 0·132 metre per month on the average, and we have already shown that the mean discharge accounts for about 610 cubic metres per second, or 0·024 metre, over the surface in a month. It follows that by far the most potent factor of the two means of lowering the level is evaporation, in about the ratio 108 to 24, or 9 to 2, and it becomes a question how far a regulator at the outlet could store water from a good season to a bad one, with a view to either navigation or irrigation purposes. The most that such a regulator could do would be to delay the maximum discharge from May till, say, November. But by this time the surface would have fallen some 25 centimetres from evaporation alone. The average maximum reading is 0·81 metre with a discharge of 670 cubic metres per second, and with a fall of 0·25 metre and a gauge-reading of 0·55 metre the discharge would

be 570 cubic metres a second. Clearly we could not hope to get the discharge corresponding to the maximum of the level.

A further consequence may be derived from the equation. We put $k=2{\cdot}7\rho+\sigma$, and found $k=1{\cdot}015$. It follows that the maximum value of the run-off is $\rho=\frac{1{\cdot}015}{2{\cdot}7}$, or 0·376, and this assumes that the rainfall on the lake surface is negligible. Again, if the rainfall on the lake is on the average equal to that round it, the run-off is reduced to 0·015. We get the following corresponding values for $\rho$ (the coefficient of run-off) and $\sigma$ (the proportion of the rainfall on the lake to that on the land):—

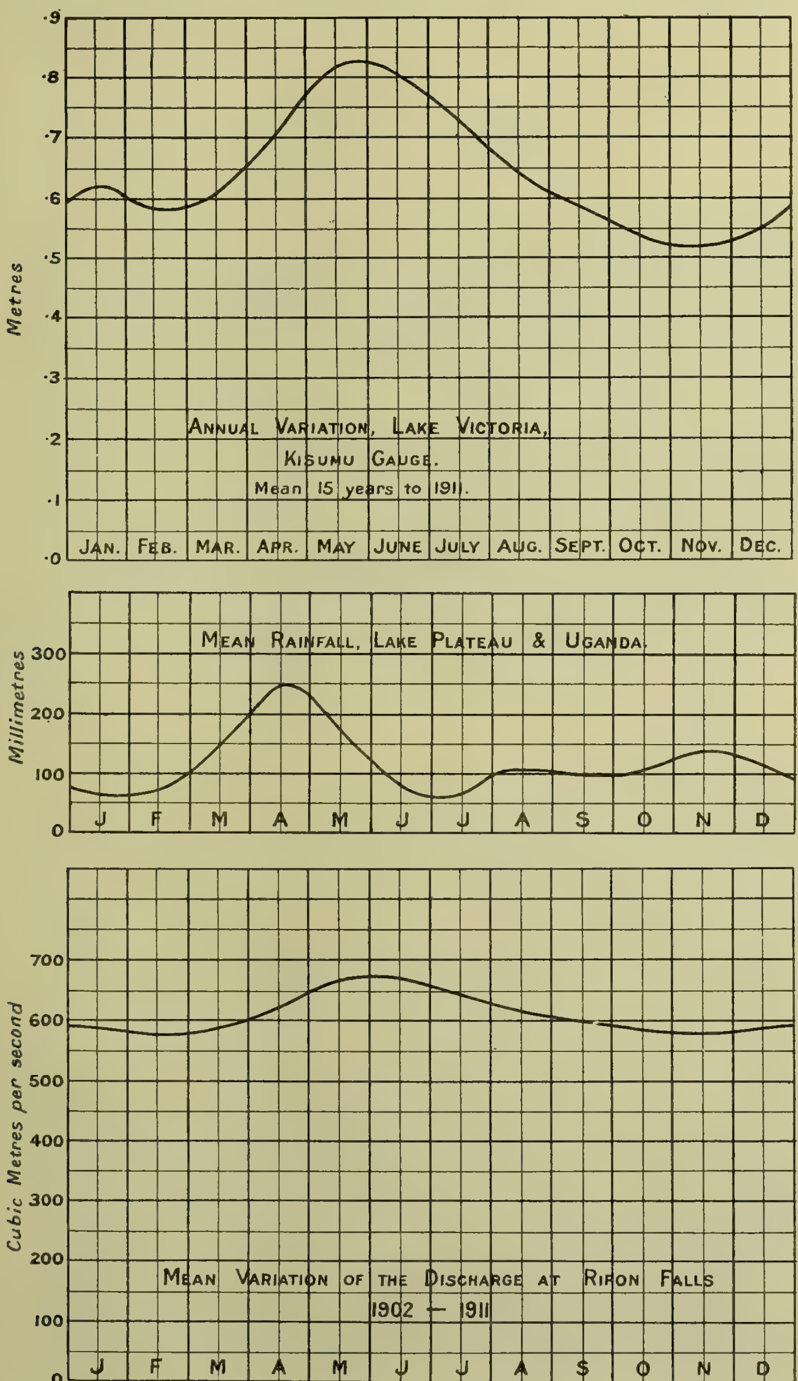
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\rho$ | 0·01 | 0·05 | 0·10 | 0·15 | 0·20 | 0·25 | 0·30 | 0·35 |
| $\sigma$ | 1·00 | 0·88 | 0·74 | 0·61 | 0·48 | 0·34 | 0·20 | 0·07. |

It appears most likely that the coefficient of run-off lies in the neighbourhood of 0·10, and that the rainfall on the lake is three-quarters of that on the land round it.

The great function of Lake Victoria in the economy of the Nile supply is to ensure a nearly constant discharge of water into the Victoria Nile, and provide much of the evaporation that comes down in the catchment basin itself in the shape of rain.

A great deal of work has been done in attempting to prove that there have been earth-movements, "crustal movements" and so on, in the north of the lake during recent—that is, contemporary as distinct from geologically recent—years, but all the discrepancies may be more simply explained as errors of the gauges. Masonry gauges have now been built by the Uganda authorities, and our knowledge of the movements of the lake level will be more precise in future. The most trustworthy gauge in the past has been that at Kisumu. With gaps of thirteen months during the Sudanese mutiny of 1897, and of two months in 1902, observations there have been continuous to the present day.

The following tables give the mean gauge-readings of Lake Victoria at Kisumu from 1896 to 1911, and the mean discharges at the Ripon Falls from 1902 to 1911:—



Metres
·9
·8
·7
·6
·5
·4
·3
·2
·1
·0
ANNUAL VARIATION, LAKE VICTORIA,
KISUMU GAUGE.
Mean 15 years to 1911.
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
MEAN RAINFALL, LAKE PLATEAU & UGANDA.
Millimetres
300
200
100
0
J F M A M J J A S O N D
Cubic Metres per second
700
600
500
400
300
200
100
0
MEAN VARIATION OF THE DISCHARGE AT RIPON FALLS
1902 — 1911
J F M A M J J A S O N D


FIG. 18.

TABLE 134.—MEAN GAUGE-READINGS AT KISUMU (LAKE VICTORIA) (in metres, corrected).

| Years. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1896 | 1·10 | 1·03 | 1·01 | 1·00 | 1·01 | 0·99 | 0·92 | 0·88 | 0·79 | 0·71 | 0·83 | 0·87 | 0·928 |
| 1897 | 0·86 | 0·91 | 0·93 | 1·01 | 0·99 | 1·07 | 1·04 | ... | ... | ... | .. | ... | } 0·982 |
| 1898 | ... | ... | ... | ... | ... | ... | ... | (1·00) | 0·99 | 0·99 | 1·00 | 1·00 | |
| 1899 | 0·95 | 0·91 | 0·89 | 0·89 | 0·99 | 0·99 | 0·82 | 0·57 | 0·52 | 0·42 | 0·41 | 0·44 | 0·733 |
| 1900 | 0·45 | 0·45 | 0·43 | 0·48 | 0·56 | 0·53 | 0·43 | 0·37 | 0·37 | 0·19 | 0·16 | 0·27 | 0·391 |
| 1901 | 0·32 | 0·37 | 0·43 | 0·68 | 0·95 | 0·88 | 0·65 | 0·49 | 0·42 | 0·35 | 0·32 | 0·24 | 0·508 |
| 1902 | 0·18 | 0·16 | 0·16 | (0·20) | (0·38) | 0·21 | 0·17 | 0·14 | 0·13 | 0·14 | 0·16 | 0·27 | 0·183 |
| 1903 | 0·37 | 0·43 | 0·44 | 0·52 | 0·73 | 0·91 | 0·96 | 0·91 | 0·93 | 0·91 | 0·90 | 0·90 | 0·742 |
| 1904 | 0·85 | 0·88 | 0·91 | 1·02 | 1·11 | 1·08 | 0·98 | 0·91 | 0·85 | 0 77 | 0·78 | 0·86 | 0·917 |
| 1905 | 0·73 | 0·72 | 0·74 | 0·83 | 0·87 | 0·84 | 0·72 | 0·64 | 0·55 | 0·50 | 0·54 | 0·67 | 0·696 |
| 1906 | 0·72 | 0·72 | 0·89 | 1·21 | 1·35 | 1·32 | 1·26 | 1·20 | 1·15 | 1·10 | 1·03 | 0·94 | 1·074 |
| 1907 | 0·93 | 0·87 | 0·82 | 0·86 | 1·08 | 1·05 | 0·94 | 0·84 | 0·77 | 0·69 | 0·69 | 0·70 | 0·853 |
| 1908 | 0·62 | 0·59 | 0·51 | 0·54 | 0·64 | 0·69 | 0·66 | 0·62 | 0·56 | 0·54 | 0·59 | 0·63 | 0·599 |
| 1909 | 0·57 | 0·52 | 0·55 | 0·57 | 0·65 | 0·62 | 0·59 | 0·50 | 0·45 | 0·45 | 0·34 | 0·34 | 0·512 |
| 1910 | 0·40 | 0·31 | 0·31 | 0·41 | 0·59 | 0·51 | 0·42 | 0·36 | 0·35 | 0·31 | 0·22 | 0·20 | 0·366 |
| 1911 | 0·13 | −0·01 | 0·11 | 0·28 | 0·36 | 0·38 | 0·33 | 0·17 | 0·07 | 0·01 | −0·02 | −0·02 | 0·149 |
| Mean | 0·612 | 0·591 | 0·609 | 0·700 | 0·811 | 0·805 | 0·726 | 0·640 | 0·593 | 0·539 | 0·530 | 0·554 | 0·642 |

The Victoria Nile, Ripon Falls.

The Victoria Nile below Ripon Falls.

The Victoria Nile, Murchison Falls.

The Victoria Nile near Lake Albert.

TABLE 135.—DISCHARGE AT THE RIPON FALLS FOR 1902 TO 1911 (in cubic metres per second).

| Years. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1902 | 459 | 453 | 453 | 465 | 492 | 468 | 456 | 446 | 442 | 446 | 453 | 488 | 460 |
| 1903 | 526 | 544 | 547 | 571 | 652 | 724 | 744 | 724 | 732 | 724 | 720 | 720 | 661 |
| 1904 | 700 | 712 | 724 | 768 | 804 | 792 | 752 | 724 | 700 | 668 | 672 | 704 | 727 |
| 1905 | 652 | 648 | 656 | 692 | 708 | 696 | 648 | 616 | 580 | 565 | 577 | 628 | 639 |
| 1906 | 648 | 648 | 716 | 844 | 900 | 888 | 864 | 840 | 820 | 800 | 772 | 736 | 790 |
| 1907 | 732 | 708 | 688 | 704 | 792 | 780 | 736 | 696 | 668 | 636 | 636 | 640 | 701 |
| 1908 | 608 | 596 | 568 | 577 | 616 | 636 | 624 | 608 | 584 | 577 | 596 | 612 | 600 |
| 1909 | 588 | 571 | 580 | 588 | 620 | 608 | 596 | 565 | 550 | 550 | 516 | 516 | 571 |
| 1910 | 535 | 504 | 504 | 538 | 596 | 568 | 541 | 523 | 520 | 504 | 471 | 465 | 522 |
| 1911 | 442 | 392 | 434 | 492 | 523 | 529 | 512 | 456 | 418 | 398 | 389 | 389 | 448 |
| Mean | 589 | 578 | 587 | 624 | 670 | 669 | 647 | 620 | 601 | 587 | 580 | 590 | 612 |

In January 1903, when the discharge on which these figures are based was taken, Kisumu gauge read 5 centimetres less than Jinja.

The photographs of the Upper Nile are taken from Sir William Garstin's and Mr Dupuis' reports in the *Basin of the Upper Nile*, by Sir William Garstin, published by the Egyptian Government in 1904.

30. **The Victoria Nile.**—From the Ripon Falls to Lake Albert the Victoria Nile has a length of 390 kilometres. The first 56 kilometres are down a slope of $\frac{1}{1100}$, in a stream varying from 300 to 500 metres in width and running between steep banks, fringed with a narrow belt of dense forest. Any project for a regulator at the Ripon Falls should contemplate development of electricity for working a railway along these 56 kilometres. The next 220 kilometres are through a flat marshy land, partly lake, partly swamps, but with the water never more than 4 to 9 metres deep. In this reach the Nile is navigable. This many-armed swamp is known as Lake Choga or Ibrahim, and its western end is traversed for some 80 kilometres by the Nile with a perceptible current, some of which is due to the rivers fed by the downflow from Mount Elgon. The northern bank is almost free from papyrus. These large sheets of papyrus and water, which cover an area of over 2000 square kilometres, must cause more loss from evaporation than they receive of direct rainfall. In this region most of the rivers so marked on the map are nothing but depressions in the rolling plains—the rush drains of Speke—whose beds are filled with dense grass or papyrus, and the proportion of the rainfall which ultimately reaches the Nile must be very small. The Victoria Nile leaves the lake in a broad stream some 900 metres wide, past Buruli station, on to Foweira. The surface of the Kafu River, which here joins the Nile, was found to be at 1032 metres altitude, at a point some 8 kilometres up from the confluence.* Allowing

* *Survey Department Report for* 1907, Cairo, 1908.

a fall of $\frac{1}{10,000}$ for the tail of the Kafu, we deduce a level of 1031 for the confluence, which is close to Buruli. The slope to Foweira may be taken as $\frac{1}{20,000}$, and the fall in 75 kilometres 4 metres. From Foweira to the foot of the Murchison Falls, the Nile falls 405 metres on a length of 79 kilometres, and then in the next 38 kilometres reaches Lake Albert. Considerable quantities of floating *pistia* weeds pass down the Victoria Nile from Lake Choga. They are well churned up between Foweira and the Murchison Falls, but finally enter Lake Albert. It would be easy to develop electricity to work a railway along these 79 kilometres.

The Victoria Nile is fed by four rivers on the right bank and three on the left. The Kafu is one of these last. Gauges have lately been put in at Kakindu and Port Masindi. The former moves like Kisumu, the latter like Butiaba. It is clear that Lake Choga has an important regulating effect, hitherto only suspected.

The catchment area of this section is 77,000 square kilometres, and the total rainfall in an average year amounts to 90 cubic kilometres, which is equivalent to a uniform rainfall of 1·17 metres per annum. The discharge below the Murchison Falls was 577 cubic metres per second on 20th March 1903, and 960 cubic metres per second on 5th September 1907. Allowing for a lag of two months (see paragraph 31), the corresponding discharges at Jinja were 530 and 740 cubic metres per second respectively. The difference represents the run-off from the basin.

31. **Lake Albert Nyanza.**—Lake Albert has an area of 4500 square kilometres, and lies about 618 metres above sea-level. We have here left the highlands of Uganda and are in the stifling heat of tropical Africa. There are considerable deposits of salt along the east shore of the lake, as there are also round Lake Edward. According to Sir William Garstin, the waters of Lake Albert are brackish near the shores, but perfectly sweet and clear in the middle of the lake. It is due to the waters of Lake Victoria that those of Lake Albert are sweet.

The catchment basin of the western lakes is 52,000 square kilometres, and the total fall of rain in an average year is 67 cubic kilometres, which is equivalent to a uniform fall of 1·29 metres per annum. The total catchment area of the Nile at its exit from this lake is 375,000 square kilometres, of which 246,000 discharge into Lake Victoria.

The shores of Lake Albert are generally steep and barren, though in places they are shelving and covered with papyrus, notably at the inlets of the Semliki River and the Victoria Nile. The lake is fairly deep and admirably suited for a reservoir.

Lake Albert is fed by the Victoria Nile on the north, the Semliki on the south, and seven streams on the east discharging very little in the dry season, and by no streams worth mentioning on the west.

The Semliki River has its sources in Lake Edward just south of the

equator, and flows into the southern end of Lake Albert, just as the Victoria Nile flows into the northern end. At one time Lake Kivu belonged to the same system, but the volcanic action of Kirunga cut off Lake Kivu, which now empties into Tanganyika. Lake Edward is shallow and occupies but a portion of what must once have been its basin, and in receding has left wide stretches of flat and generally marshy ground. From the low ground, to east and west, rise steep escarpments—the edges of the rift in which the lake lies—to heights of from 300 to 600 metres. Lake George or Dueru, which is joined to Lake Edward in the north-east by a long winding channel from 400 to 1200 metres wide between its high banks, lies in open country at the south-east side of Ruenzori, whose drainage it receives. Some small lakes in the neighbourhood are so saline that they are worked by the natives for salt for local use.

The combined area of these two lakes is about 2580 square kilometres. The altitude of Lake Edward is about 915 metres, and its greatest dimensions some 78 by 48 kilometres. Its waters, as described by Sir William Garstin, are green in colour and brackish.

The Semliki discharges the surplus waters of the lake, and may be considered as having a discharge of 100 cubic metres per second as a minimum, and 400 cubic metres per second as a maximum. It is described by Major Bright * as a fine river from 55 to 90 metres in width, which would be navigable throughout its length in the rainy season but for the falls and rapids in the neighbourhood of the Congo station at Beni. In some 120 kilometres of its length this river traverses the eastern end of the Congo forest, and the day may not be far distant when this timber will be floated down the Semliki, towed across Lake Albert, and sent down the Albert Nile to Gondokoro and Khartoum. The fall of the Semliki, according to accepted levels, is 293 metres in 248 kilometres.

Lake Albert is at its highest in December and at its lowest in April. For this there are two reasons. First, the local rainfall round Lake Victoria reaches a secondary maximum in November, which sends an increased volume of water into the Victoria Nile at a time when the channel is already well filled. It will be shown later that there is a lag of almost exactly two months (on the average) between a rise on Lake Victoria and its effect on Lake Albert, and this would cause a secondary maximum on the lower lake in January. Secondly, the rains round the lake itself reach their maximum in November, and the run-off from the steep catchment basin reaches its maximum almost at once; and all round the basin the run-off is probably greater, as the ground is damper after the summer rains. This would lead to a November maximum. The net result is a maximum in neither month, but between the two—in December.

Apart from the periodic influence of the one lake on the other, the

* *Geog. Jour.*, vol. xxxiv., 1909, p. 135.

non-periodic effect is so considerable that it may be said that the variations of the one follow those of the other nearly proportionally, but the closeness of the effect is greatest when allowance is made for a lag of nearly two months. If we eliminate the periodic parts of the monthly variations, correlate the non-periodic parts for the interval 1904 to 1911, and calculate the coefficient of correlation $r$, we obtain the following results:—

| | |
|---|---|
| With no lag . . . . . . . . . | $r$ +0·883 |
| „ a lag of one month . . . . . | 0·899 |
| „ „ „ „ two months . . . . . | 0·901 |
| „ „ „ „ three months . . . . . | 0·896 |
| „ „ „ „ four months. . . . . . | 0·879 |

The steady rise of these numbers to a maximum close to two months and their steady fall again show that we must be dealing with a real effect; and that the deviations of Lake Albert are almost entirely due to those of Lake Victoria, or to some other cause (such as the rainfall) on which both are dependent in about the same degree. It cannot be the correlation of the rainfalls round the two lakes, for that round Lake Victoria drains off within the month (see paragraph 30), and that round Lake Albert must drain off even faster, and the lag could not be accounted for. But it may be due to correlation of the rainfall in the basin of the Victoria Nile with that round Lake Victoria, and that this is partially the case is to some extent supported by the greater mean deviation of Lake Albert (0·33 metre) than that of Lake Victoria (0·28 metre). If this is so, it is certain that the lag of two months is a mean between two lags—say, one of one month or less for the Victoria Nile basin, and a longer one of three or even four months for the wave from the Victoria Lake. However the effect may ultimately be analysed, it is now abundantly clear that the deviations of Lake Albert are controlled by those of the Victoria Nile, and the position that the latter has a constant discharge at Buruli must be abandoned.

A reference to paragraph 25 will show how great is the regulating effect of Lake Albert on the Nile. As above indicated, there is a delay of two months (or possibly even more) in the passage of the floods of Lake Victoria to Lake Albert, and there will be a still greater delay in their passage to the outlet. A rise of 1 metre at Butiaba gauge means an increased volume of 4500 million cubic metres in the lake, and as the discharge at Nimulé rises slowly at first and more rapidly later, the lake level gains at first on the discharge at the outlet, but becomes stationary later, when the discharge is just equal to the inflow. We shall consider afterwards (in CHAPTER XII.) the effect of building a regulator on the Albert Nile to utilise this storage capacity.

Table 136 gives the mean discharge from Lake Albert at Wadelai for each month from 1902 to 1911. The mean annual total is 24·8 cubic kilo-

metres. Since the mean annual total discharge at Jinja amounts to 18 cubic kilometres, only 6·8 cubic kilometres are contributed by the 67 cubic kilometres of rainfall of the western lake basin. The run-off is thus just over 10 per cent., and the effect of the basin of the Victoria Nile is only about one-third of that of Lake Victoria.

TABLE 136.—MONTHLY MEAN DISCHARGE AT WADELAI
(in cubic metres per second).

| Years. | Jan. | Feb. | Mar. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1902 | 626 | 582 | 568 | 542 | 563 | 546 | 556 | 578 | 609 | 638 | 713 | 738 | 605 |
| 1903 | 710 | 682 | 654 | 642 | 662 | 716 | 774 | 816 | 876 | 972 | 1039 | 1064 | 801 |
| 1904 | 1058 | 1026 | 991 | 1000 | 1007 | 1004 | 1007 | 1045 | 1058 | 1058 | 1084 | 1084 | 1035 |
| 1905 | 1069 | 1064 | 909 | 772 | 772 | 774 | 763 | 758 | 774 | 804 | 801 | 870 | 844 |
| 1906 | 837 | 801 | 783 | 774 | 777 | 774 | 783 | 798 | 852 | 858 | 888 | 879 | 817 |
| 1907 | 846 | 816 | 792 | 772 | 792 | 789 | 786 | 798 | 813 | 801 | 774 | 766 | 795 |
| 1908 | 769 | 756 | 745 | 736 | 731 | 725 | 724 | 726 | 741 | 736 | 748 | 773 | 742 |
| 1909 | 770 | 756 | 744 | 745 | 760 | 762 | 761 | 759 | 774 | 782 | 778 | 776 | 764 |
| 1910 | 764 | 754 | 744 | 742 | 742 | 740 | 730 | 730 | 742 | 754 | 758 | 758 | 746 |
| 1911 | 740 | 734 | 729 | 724 | 718 | 713 | 710 | 704 | 707 | 704 | 702 | 707 | 716 |
| Mean | 819 | 797 | 766 | 745 | 752 | 754 | 759 | 771 | 795 | 811 | 828 | 842 | 787 |

32. **The Albert Nile.**—The Albert Nile, or the Bahr el Jebel, has a length of 1287 kilometres from Lake Albert to the mouth of the Sobat River. For 218 kilometres, past Wadelai to Nimulé, it flows in a broad stream with a sluggish current as a rule, and is covered with islands and papyrus marshes. This reach of the Nile is navigable. The fall here must be very little, and it may be considered as 4 metres. In high floods enormous quantities of pistia weeds float down this reach of the Nile. Papyrus and ambatch are very common along the shores and on the islands. As the river approaches Nimulé it contracts, turns an abrupt right angle, and enters the rocky gorge of 148 kilometres in length which induced the early Arabic voyagers to call the stream "Bahr el Jebel." The granite beds of Nimulé would be an excellent site for a reservoir dam. The work would be an economical one, as the discharge need never exceed 1200 cubic metres per second of clear water.

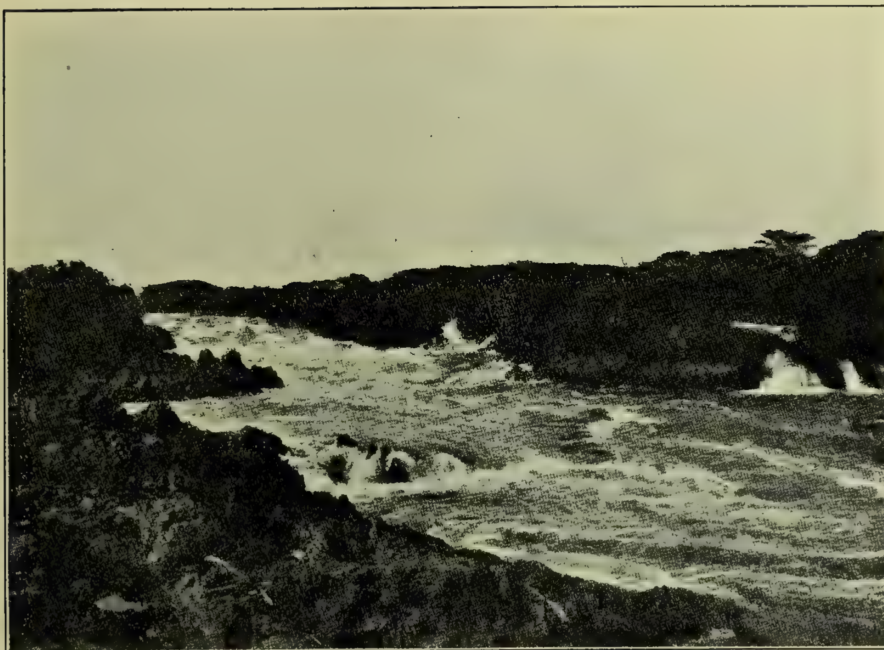
At Nimulé begin the Fola Rapids, followed by numerous cataracts down to Fort Berkeley, south of Gondokoro. In this reach the river falls 159 metres. The green water of the upper reaches is purified in its passage through these cataracts. The rock is granite. If the regulator for Lake Albert were constructed near Nimulé, it should contemplate development of electricity for working a railway along these 150 kilometres, but Colonel Delmé-Radcliffe considers that the river might be made navigable up to the foot of the Fola Rapids.

South of Nimulé the principal tributaries of the Albert Nile are on the right bank, viz.: the Achua and Umi. In the dry season they are dry, but after rains they may add some 50 cubic metres per second to the river. Between Nimulé and Fort Berkeley many rivers flow into the Albert Nile, notably the Asua. In the dry season all but the Asua are dry. The left-bank tributaries are numerous, but insignificant. The volume discharged by these streams in the rainy season is very considerable, as will be seen if the discharges at Mongalla are compared with those at Wadelai. They are amongst them capable of increasing the discharge of the Albert Nile for short intervals of time by 1500 cubic metres per second. All these streams are torrential and rise and fall quickly.

From Fort Berkeley to Khartoum, the Albert and White Niles are navigable. From Fort Berkeley to Mongalla, past Gondokoro, on a length of 72 kilometres, the Albert Nile falls 13 metres, has a very good velocity and slope, and, broadly speaking, may be said to flow within its banks. The maximum discharge is 2500 cubic metres per second and the minimum 500.

From Mongalla to Bôr, on a length of 125 kilometres, the river falls 20 metres, and in low supply is within its channel. There are numerous spills into side lakes and depressions. The river flows in a valley from 7 to 12 kilometres wide and is decidedly deltaic. In summer the level of water in the river is 2·5 metres higher than that in the furthest side depression. The range between high and low supply is consequently much greater at Mongalla than at Bôr, being 2 metres at the former and 1 metre at the latter. In flood the whole valley is inundated, and much of the water which passes Mongalla is utilised in filling this huge basin. This accounts for the difference in discharge at Mongalla and Bôr being only 15 (520 — 505) cubic metres per second in extreme low supply and 1150 (2050 — 900) cubic metres per second in high supply. This water is not lost, but displaced, and its influence has yet to be studied. The width of the river may be taken as 250 metres at Mongalla and 150 metres at Bôr, with a depth at the former of 4 to 6 metres, and at the latter of 4 to 5 metres. The velocity ranges from above 1 metre per second in flood to 75 centimetres in low supply.

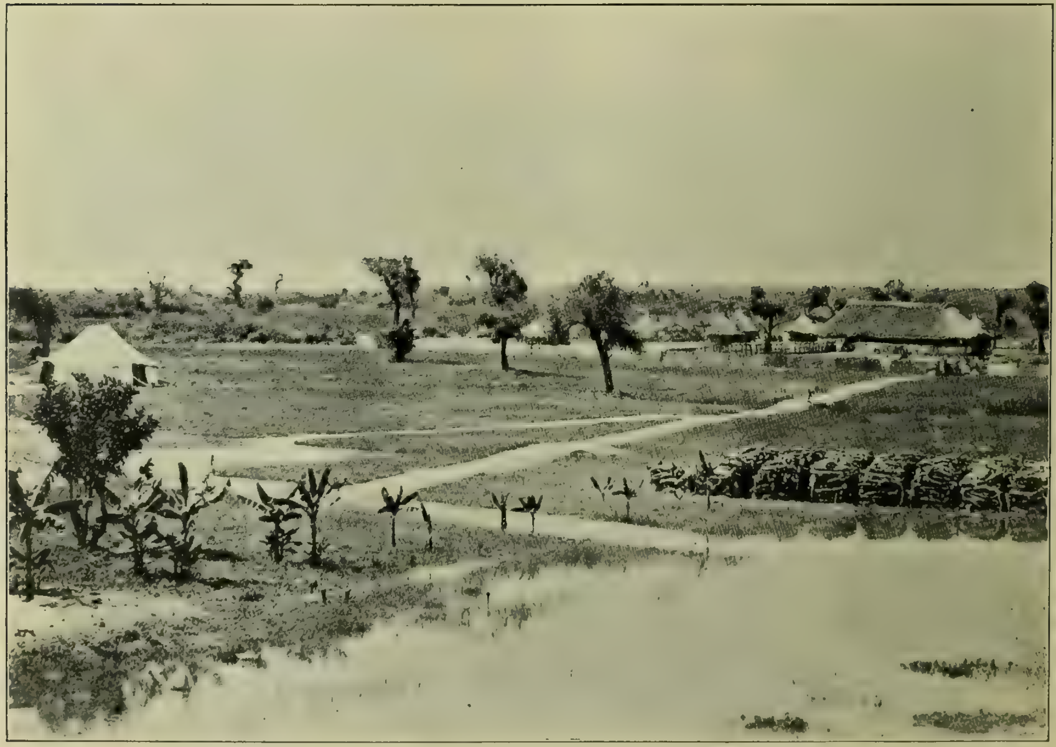
From Bôr to Ghaba Shambe, on a length of 183 kilometres, the river falls 15 metres, and though very freely overflowing its banks in flood, still flows in low supply within banks of some kind formed of sandy deposit and covered with grasses. The spills here are very numerous. The inundated valley may be considered to be roughly 20 kilometres wide. The range between high and low supply at Ghaba Shambe is 1 metre, the same as at Bôr. We may take the width of the river as varying from 150 to 60 metres and the depth from 5 to 6 metres. The velocity ranges from 80 centimetres per second to 60. In this reach the river experiences great



The Albert Nile, Fola Rapids.

The Albert Nile, Fola Rapids.

The Albert Nile near Gondokoro.



The Albert Nile, Mongalla.

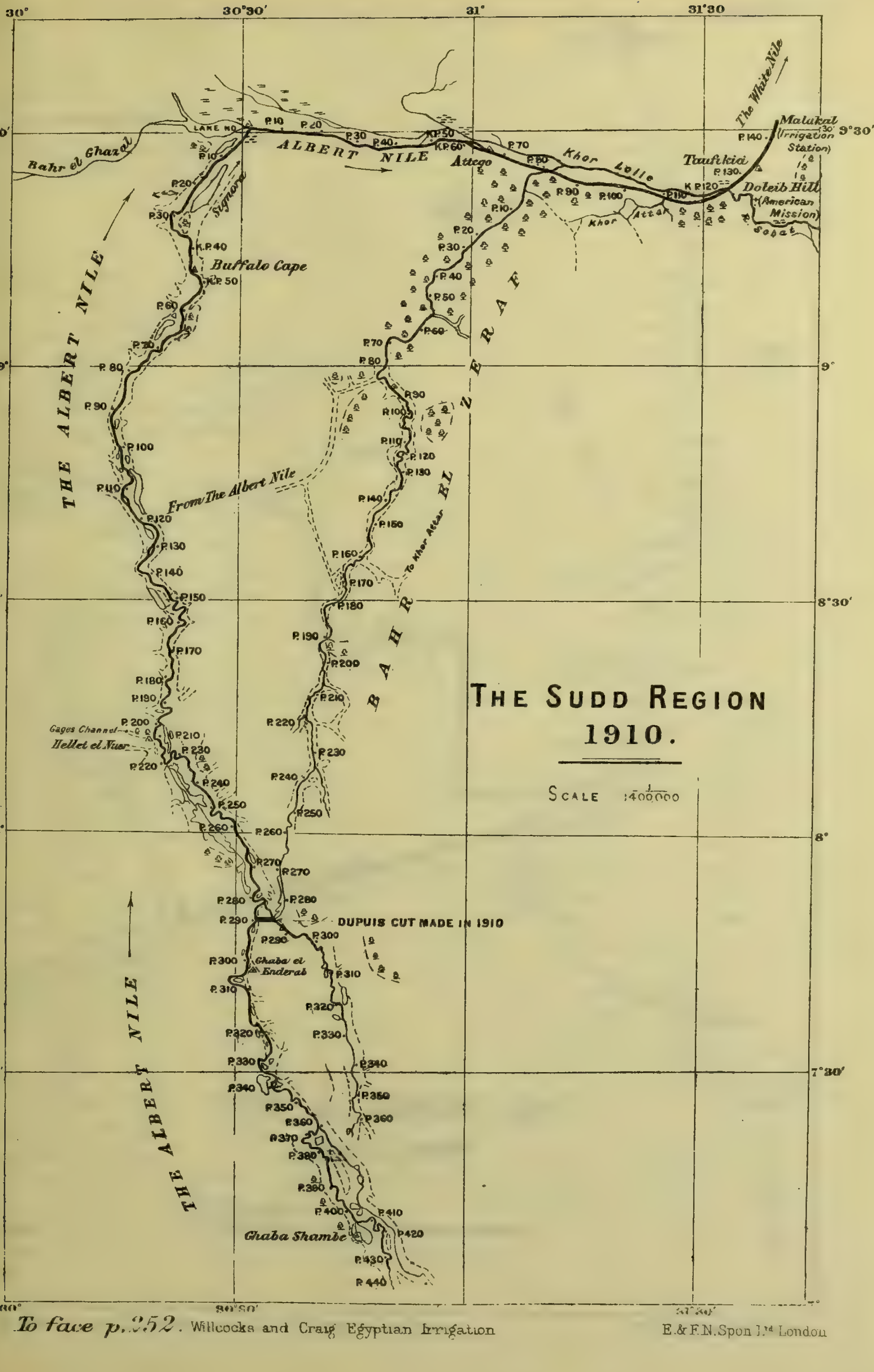
changes. From measured discharges in December 1910 and January 1911 we learn that the Albert Nile at Bôr was then discharging 730 cubic metres per second. Downstream of Bôr, the Atem river was taking off from the right bank of the Nile and draining a small quantity of water at its head. At intervals of between 30 and 40 kilometres below Bôr the discharges of the Albert Nile were 650, 400, 380, and 360 cubic metres per second. At the last site 130 cubic metres per second passed into the Atem or Awai on the right, and then the discharge of the Albert Nile fell to 240 cubic metres per second. Before Ghaba Shambe was reached, the Awai returned 260 cubic metres per second into the Albert Nile and carried forward 130 in its own channel. Downstream of Ghaba Shambe the Albert Nile discharged 470 cubic metres per second. Before Ghaba Shambe is reached the grasses have given place to papyrus, which now accompanies the Nile to Lake No. The grasses grow where the soil is mud or sand, and the papyrus where the soil is principally decayed vegetation. The banks of the river begin to disappear. The Albert Nile preserves its deltaic character, but not in so marked a way as upstream of Bôr.

From Ghaba Shambe to Lake No, on a distance of 419 kilometres, the Albert Nile falls 18·4 metres. This is the true Sudd region of the Nile. We shall divide it into two reaches : one from Ghaba Shambe to Hillet Nuêr, and the other from Hillet Nuêr to Lake No.

Between Ghaba Shambe and Hillet Nuêr, on a length of 194 kilometres, the Albert Nile falls 8·60 metres. The width of the river may be taken as from 100 to 120 metres where the discharge is above 350 cubic metres per second, and 60 metres where the discharge is low in the reach blocked by sudd No. 15 upstream of Hillet Nuêr. The depth is from 5 to 7 metres. The velocity ranges from 60 to 80 centimetres per second. In this reach the Zeraf River takes off on the right bank and is fed by overflows from the Awai or the Atem from the south, and overflows from the Albert Nile and through the new or Dupuis' cut just upstream of Baker's cut. The inundated valley, omitting the Zeraf River, may be taken here as 15 kilometres wide in the south and 25 in the north, or 20 kilometres on the average. On the left the valley is well defined for this part of the world ; but on the right the waters of the Albert Nile and the Zeraf mingle in flood and form one sheet. The Albert Nile is always higher than the Zeraf even in flood, but in low supply the Albert Nile is 1 metre higher than the Zeraf, and there is a steady draw in that direction. This should be remembered. The Albert Nile is deltaic, feebly so, but unmistakably. Its banks, nearly always in low supply, and invariably in flood, have a depth of water from 0·50 to 1·50 metres above them. The papyrus grows in the water and stands like a low forest on either hand. Its height is some 6 metres. The maximum range at Ghaba Shambe is 1 metre, but in a mean year it is 50 centimetres. At Hillet Nuêr the maximum range is 50 centi-

metres. The river here is winding its way through an apparently interminable lake of water, out of which grows the papyrus, with its roots often 3 metres below the surface of the water. As a rule the Albert Nile water is a little higher than that on either side. We shall now follow the Albert Nile with its discharges in December 1910 and January 1911 as we did upstream of Ghaba Shambe. We have seen that the discharge some 10 kilometres downstream of Ghaba Shambe was 470 cubic metres per second, with the Awai on its right hand taking on 130 cubic metres per second. Some 20 kilometres lower down the Albert Nile was discharging 400 cubic metres per second, and 20 kilometres lower down the Awai brought in 270 cubic metres per second, and the discharge of the Albert Nile rose to 590 cubic metres per second. Twenty kilometres lower down this had fallen to 460 cubic metres per second, and then increased to 620 cubic metres per second 20 kilometres further down again. Here very considerable overflows took much water to the west, and at Ghaba Inderab the discharge was reduced to 370 cubic metres per second. Dupuis' cut to the Zeraf takes off a little below Inderab, and just above it the discharge was 350 cubic metres per second. The cut took off some 90 cubic metres per second, but shortly below it a considerable influx from the left swelled the Albert Nile to some 450 cubic metres per second. We ask the reader to remember this fact. A few kilometres below the influx, nearly half the water of the Albert Nile went off to the left down the blind channel which had to be used for navigation from 1899 to 1904 till sudd block No. 15 was removed. In this reach of 45 kilometres from here to Hillet Nuêr the discharge of the Albert Nile falls to 250, while 200 cubic metres per second is flowing down the blind channel. Just before Hillet Nuêr is reached this channel discharges its water back into the Albert Nile, and the discharge near Hillet Nuêr rises to 450 cubic metres per second. Here Gages' Channel leaves the Albert Nile on the left, and drains off from 10 to 20 cubic metres per second. We have the river fairly concentrated at Hillet Nuêr.

From Hillet Nuêr to Lake No, on a length of 225 kilometres, the Albert Nile falls 9·4 metres. The width of the river may be taken as between 80 and 120 metres, with 6 or 7 metres depth of water. The velocity runs from 0·60 to 0·80 metre per second. The greatest range of the river at Hillet Nuêr is about 0·50 metre. At Buffalo Cape, 50 kilometres upstream of Lake No, the range is only 0·20 metre, and this is due to backwater thrown up by the Sobat in flood lower down. The range at Lake No is 1 metre, and is due entirely to the same backwater. In this reach there are two or three overflows into the Zeraf on the right through wide shallow depressions between the two rivers, but the mass of the water which the river loses goes off into the wide marsh on the left hand, of which Lake No is the lowest point. The wide stretch of marsh, papyrus, grasses, and maybe damp




*To face p. 252.* Willcocks and Craig Egyptian Irrigation

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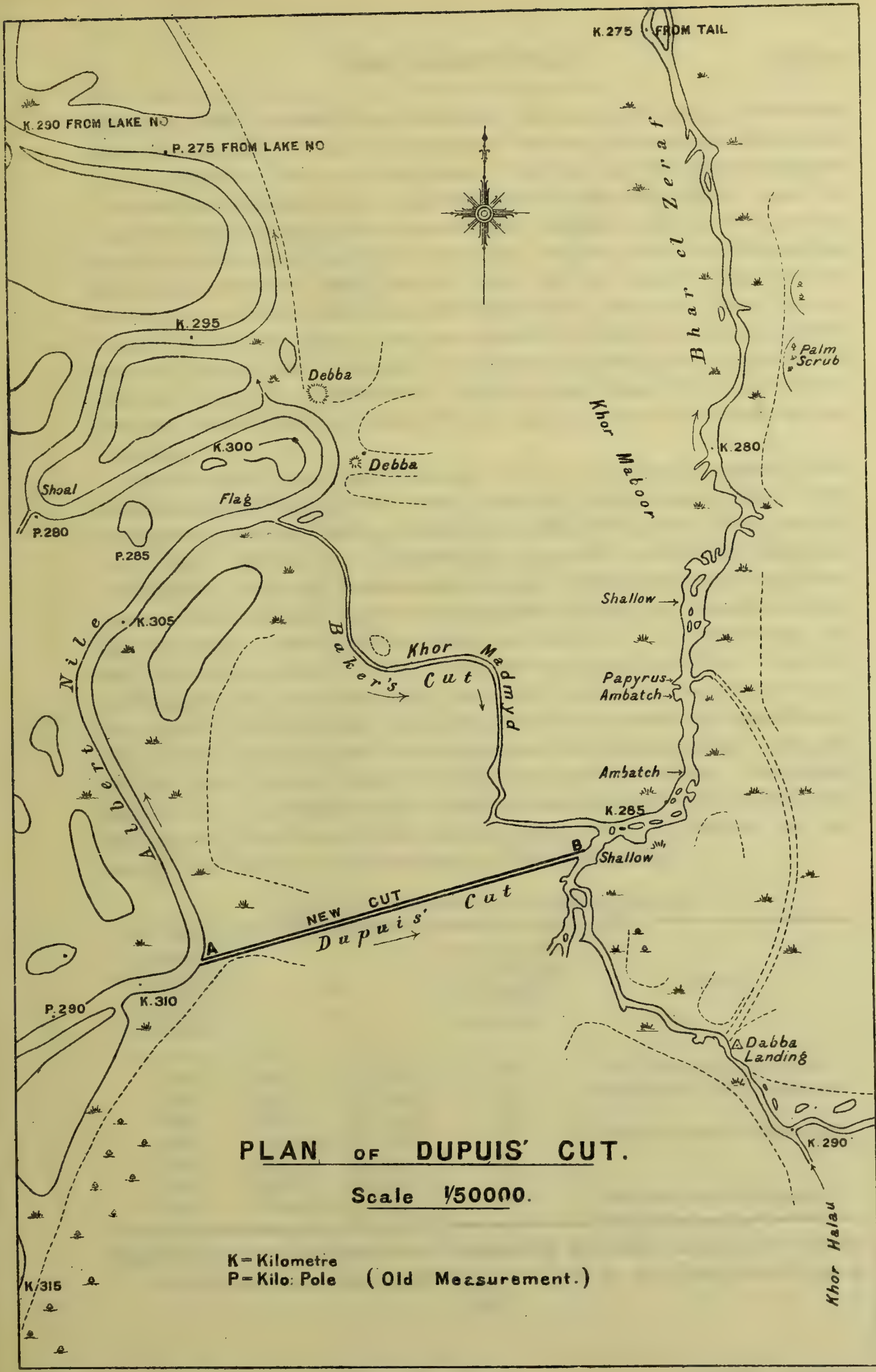

K.275 FROM TAIL
K.290 FROM LAKE NO
P.275 FROM LAKE NO
Bhar el Zeraf
K.295
Debba
Palm Scrub
Khor Maboor
K.300
Debba
K.280
Shoal
Flag
P.280
P.285
Shallow
K.305
Nile
Baker's Cut
Khor Madmyd
Papyrus
Ambatch
Albert
Ambatch
K.285
B
Shallow
NEW CUT
Dupuis' Cut
A
P.290
K.310
Dabba Landing
K.290
Khor Halau
K/315
PLAN OF DUPUIS' CUT.
Scale 1/50000.
K = Kilometre
P = Kilo: Pole
(Old Measurement.)

forest in places, is some 130 kilometres wide and 160 long. The water here rises and falls between 0·20 metre at Buffalo Cape as a minimum and 1·20 at Meshra el Rek as a maximum. We may say that on this area of 10,000 square kilometres the range of water is some 0·60 metre. Lake No may appear small, but it is surrounded by papyrus which grows in 2 or 3 metres of water as well as it does on damp soil, and how far this papyrus goes back no human being knows. Into this vast area of swamp on the left of the river the Albert Nile, between Hillet Nuêr and Lake No, discharges some 100 cubic metres per second, of which 20 cubic metres is returned at Lake No. The net loss is therefore 80 cubic metres per second. This fact should be remembered. As far as the Albert Nile is concerned, between Hillet Nuêr and Lake No the loss of water is 80 cubic metres per second.

On the right hand the submerged area is not serious outside of the shallow depressions, and may be put down at 5 kilometres in width. We shall now follow the discharges down the Albert Nile from Hillet Nuêr to Lake No in March 1911. Discharging 450 cubic metres per second at Hillet Nuêr, it was still discharging 450 cubic metres 60 kilometres down. Some 20 kilometres lower it was discharging 430, and 30 kilometres below that 430 again. Some 50 kilometres lower down it was discharging 350, and 350 cubic metres per second were flowing into Lake No. The river at Mongalla was only discharging 600 cubic metres per second, so that it was near its lowest stage. All down this reach there has undoubtedly been scour since the sudds were removed, the channel kept open, and the clear water allowed to cut its way through the marshes. Comparing recent with old sections in the decayed vegetable soil from Hillet Nuêr downstream, the channel has widened from 10 to 15 metres, but not become much deeper. The following table is interesting:—

TABLE 137.—DISCHARGE ENTERING LAKE NO.

| Discharge of the Albert Nile at Mongalla. Cubic metres per second. | Date. | Discharge at the Albert Nile into Lake No. Cubic metres per second. | Remarks. |
|---|---|---|---|
| 500 | April 4, 1900 | 220 | Very low year at Mongalla. |
| 690 | April 12, 1903 | 290 | Sudd block No. 15 removed. |
| 1130 | May 22, 1904 | 320 | Very high year at Mongalla. |
| 1100 | February 28, 1906 | 330 | |
| 1100 | May 31, 1906 | 340 | |
| 600 | March 12, 1911 | 350 | |
| 550 | February 4, 1912 | 360 | Very low year at Mongalla. |

Dupuis' cut into the Zeraf was discharging 70 cubic metres per second.

The Albert Nile from Lake No to its tail at the Sobat mouth has a

length of 127 kilometres, and falls about 1·1 metres in high flood when the Sobat holds up water on Lake No, and about 3·6 metres in low supply when the Sobat discharge is a negligible quantity. The slope in extreme flood is therefore $\frac{1}{120,000}$ and in low supply $\frac{1}{40,000}$. The maximum range at Lake No between low supply and high flood is about 1 metre. The range at the tail of the Albert Nile is 3·6 metres. The width of the Albert Nile downstream of Lake No may be taken as 150 metres in low supply and flood; and the depth 3·6 metres in low supply, and 4·6 in flood. At the tail it may be taken as 300 metres in low supply and 400 metres in flood, and the depth in low supply as 2·5 metres, and in flood as 5 metres. The velocity in flood may be taken as 0·30 metre, and in low supply as 0·60, but there are great differences between one part of the channel and another.

In this reach the river in low supply is within its banks, in a well-formed and well-maintained channel at first, which near the tail of the Albert Nile widens out into a broad shallow basin. This last formation is imposed on the river by the floods of the Sobat, which hold it back. The left bank is everywhere inundated in flood for many kilometres, especially near Lake No, where the country falls away as one leaves the lake. At a distance of from 6 to 1 kilometre, flows the Lolle, a sluggish stream, nearly always sudded, with a discharge of from 30 to 160 cubic metres per second according to locality. No one knows whether this stream is really in communication with the Gazelle River or not. On the right bank of the Albert Nile there is a continuous papyrus marsh for 16 kilometres until the Maya Signora brings in all the overflow water of the right bank from Buffalo Cape to Lake No. From here on the right bank is well defined and covered with grasses. The papyrus-covered swamps disappear, and we are out of the deposit of the Albert Nile. We have to do with honest soil, covered with grasses and generally with acacias, and probably deposited by the Sobat when it flowed into the lake of which Lake No is the relic. Eighty kilometres below Lake No the Zeraf River flows back into the Albert Nile and brings in a discharge of from 70 to 200 cubic metres per second, and some kilometres lower down the Megahid River flows in and adds its quota in flood to the general swamping. Just before the tail is reached, the Lolle joins the Albert Nile on the left, but sends off a branch to the left, which flows into the White Nile above Malakal. Downstream of the Maya Signora the papyrus is confined to the water's edge, and that only occasionally.

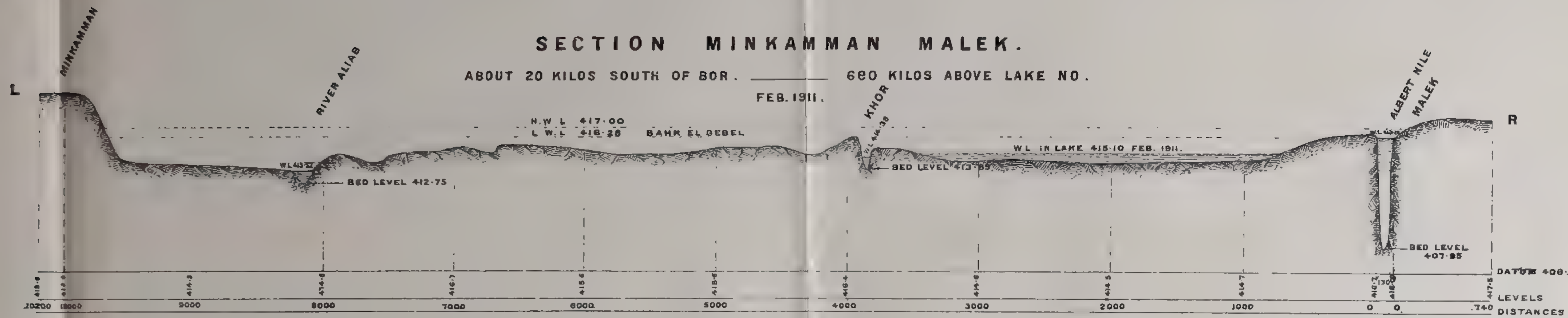
The main tributaries of the Albert Nile between Fort Berkeley and Bôr are:—on the east bank, the Kit second only to the Asua, and the Lokadero; between Ghaba Shambe and Hillet el Nuêr on the left bank, three channels flow into the Albert Nile. These are considered to be the tails of the River Yei, but this is very doubtful.

# TYPICAL CROSS SECTIONS OF THE ALBERT NILE.

## SECTION MINKAMMAN MALEK.

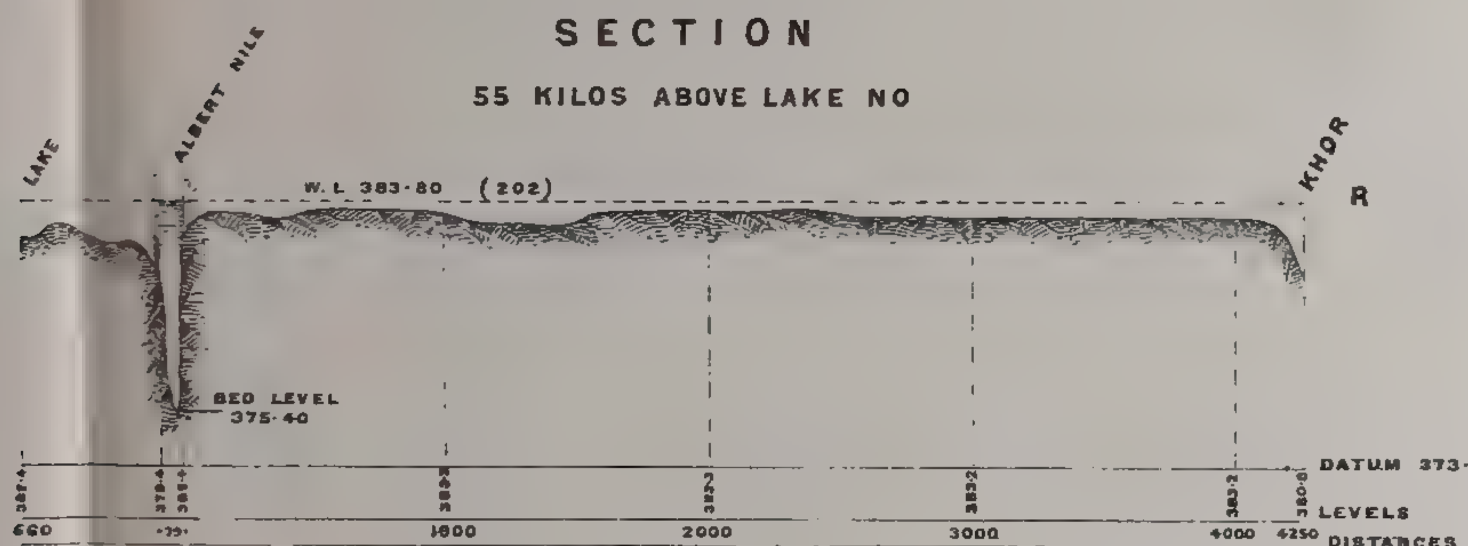
ABOUT 20 KILOS SOUTH OF BOR. ——— 660 KILOS ABOVE LAKE NO.

FEB. 1911.



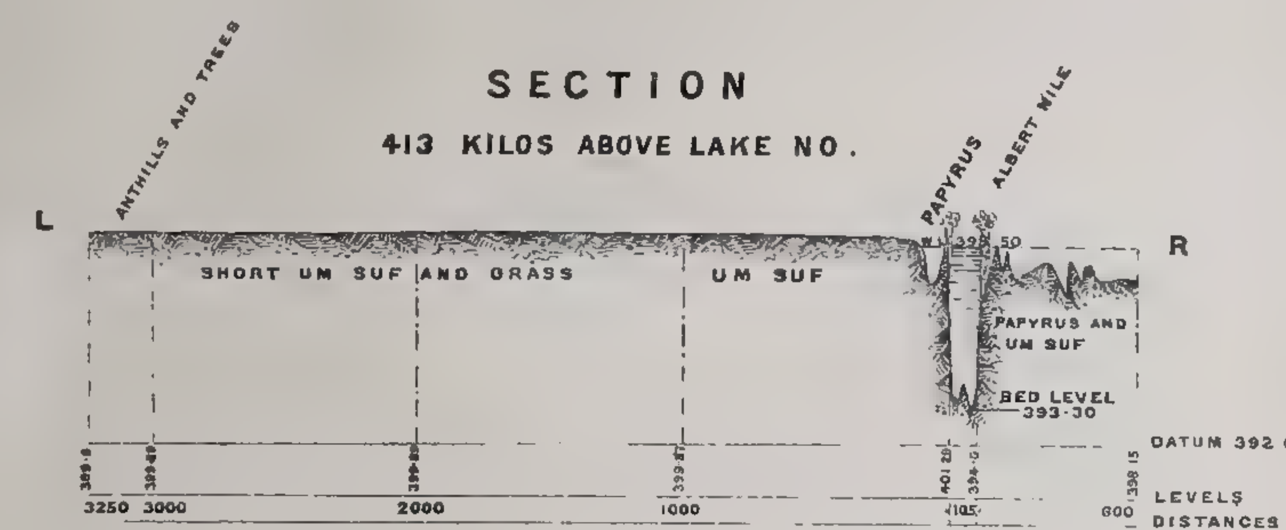

## SECTION

55 KILOS ABOVE LAKE NO




## SECTION

413 KILOS ABOVE LAKE NO.




*To face p. 274.* Willcocks and Craig Egyptian Irrigation

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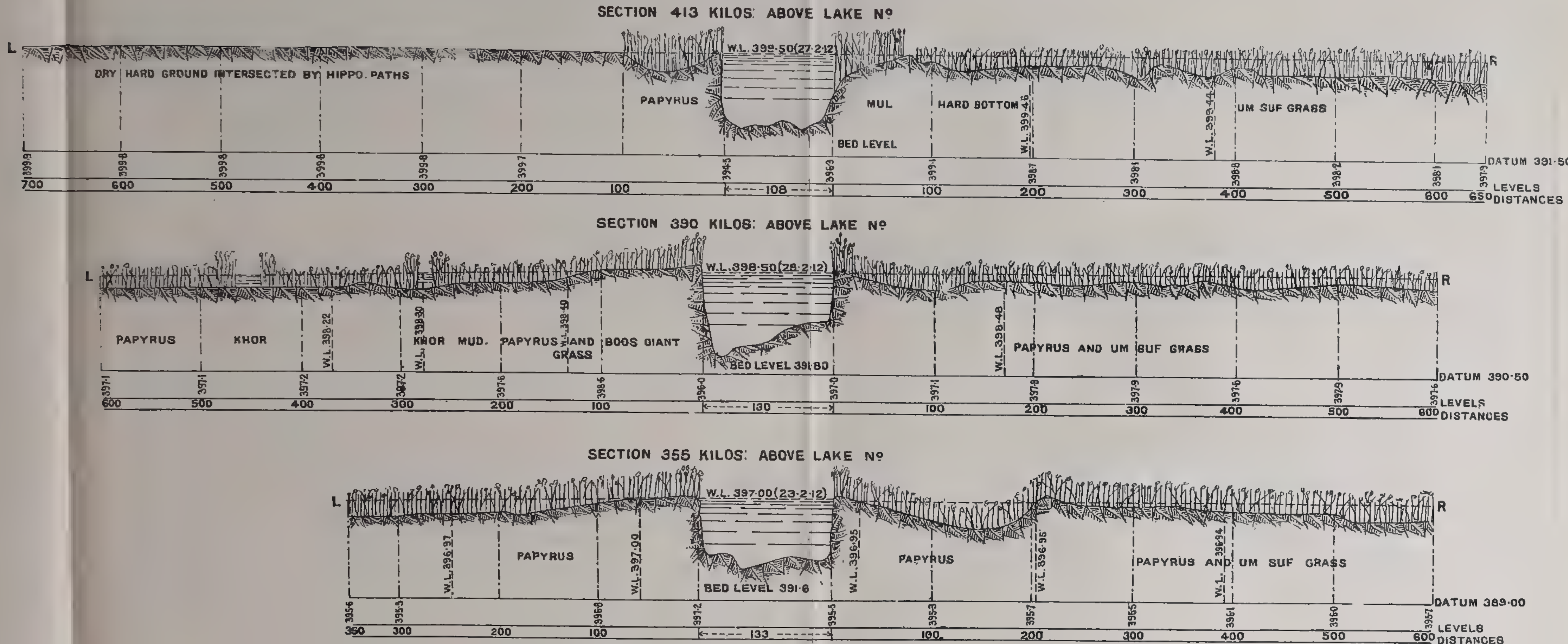
# TYPICAL CROSS SECTIONS OF THE ALBERT NILE,

## BETWEEN GHABA SHAMBE AND HEAD OF CUT (DUPUIS)

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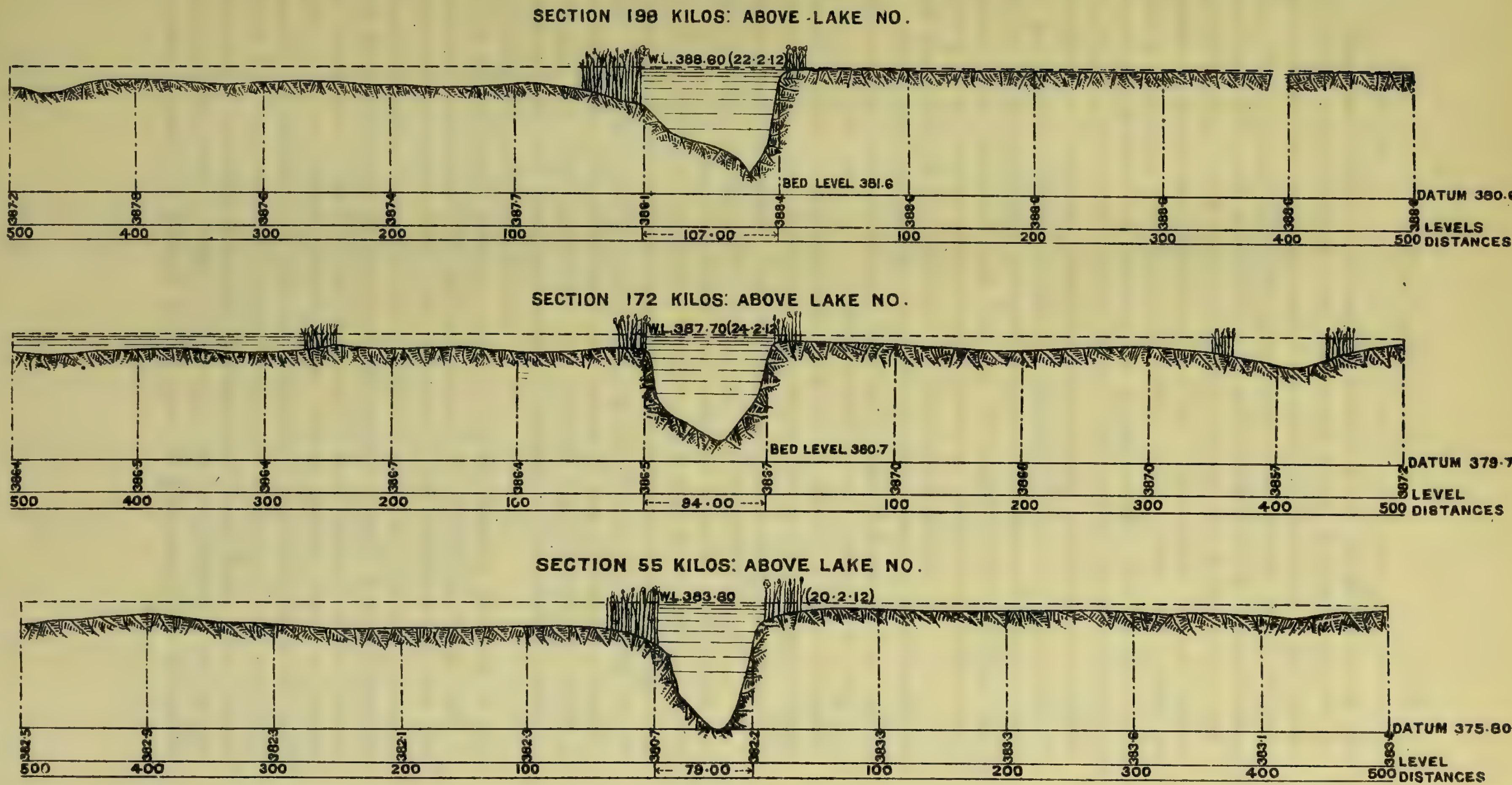
# TYPICAL CROSS SECTIONS OF THE ALBERT NILE,

## BETWEEN HEAD OF CUT (DUPUIS') AND LAKE NO.




*To face p. 254.* Willcocks and Craig Egyptian Irrigation.

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From Bôr to some 100 kilometres south of Lake No the course of the River is extraordinarily like the Mississippi south of Vicksburg, with its severe curves and ox rings which correspond to the *mayas* of the Albert Nile. There is a great family resemblance to the courses of the Kagera, the Pibor, the Rahad and Dinder, and other rivers flowing through plains on a low slope. Such mayas or lagoons can be seen in the last 20 kilometres of the Rosetta branch of the Nile. This deltaic form is readily seen in the cross sections of the valley of the Albert Nile, although not so well marked as in the valley in Egypt proper. This is due to the fact that the Albert Nile collects all its sediment from the basin between Nimulé and Gondokoro, where the soil is largely protected from erosion by an extensive covering of tropical vegetation, whereas in the basins of the Blue Nile and Atbara the southern limit of the desert is being neared, the soil is less protected, both from the disintegrating effect of solar heat during the dry season and the eroding power of the rain in the wet season, and the amount of the sediment is in consequence greater.

Between Ghaba Shambe and Lake No there were 19 sudd blocks, of which all but one were removed by Major Peake, R.A., and Lieut. Drury, R.N., in 1900 and 1901. Their positions are indicated on fig. 19. South of Hillet el Nuêr was sudd block No. 15, where the original channel was closed by a boat laden with ivory sinking in the true channel during the Dervish domination. The boat was found, the ivory recovered, and the work of sudd clearing commenced in 1902 and completed in 1904.

The water of the river is clear in low supply from the head to the tail of the Albert Nile. In flood it is more or less clear from Lake Albert to Nimulé, and laden with sand from the tail of the Asua, past Mongalla to Bôr. The sand gradually diminishes as the waters flow in and out of the marshes and become clearer and clearer as one advances northwards. Through the Sudd region, and especially the northern half, the water is dark-coloured and practically without sediment. Very little ambatch is met with north of Ghaba Shambe.

It seems highly probable that the region between the foot of the equatorial plateau and the southern slopes of Kordofan was at one time a shallow lake, similar to the Lake Choga or Lake Chad of to-day and the Lake Victoria or Lake Albert of a distant to-morrow. The mere shape of the depression is enough to suggest by analogy a stage in the life-history of this portion of the river that is known to have occurred in the case of other rivers in similar circumstances. But in addition there is positive evidence of the existence of an old beach in the shelf along the north bank of the Lolle on which the Dinka villages are clustered. The centripetal drainage of the Albert Nile, Bahr el Ghazal, and Sobat River shows that we are not dealing with a normal river valley. And the existence of "kitchen middens" near Kio, covered with a layer of soil some 90 or 100 centi-

metres deep, suggests possible lake-dwellings. And the prevalence of kunkar points to lacustrine rather than fluvial conditions.

De Martonne (*Traité de géographie physique*, Paris, 1909, p. 431) says: "Les plaines d'inondation peuvent se former dans les bassins des grands fleuves, même dans l'intérieur d'un continent. Ainsi elles sont particulièrement fréquentes en Afrique (plaine du moyen Niger près Tombouctou, plaine du Nil en amont de Fashoda, plaine du Congo) et même en Europe (plaine hongroise). Elles marquent alors presque toujours la position d'un lac intérieur disparu. Avant que les eaux du Niger aient réussi à s'échapper vers le golfe de Guinée, la dépression de Tombouctou devait ressembler à ce qu'est actuellement la cuvette du Tchad où débouche le Chari. Il en a été certainement de même du Congo et du Nil."

The following table shows the difference in water-level between high flood and low supply, and in the discharges between Mongalla and the Sobat mouth on the Albert Nile.

TABLE 138.—DISCHARGES OF THE ALBERT NILE.

| Nearest Locality. | Kilometres from Mongalla. | R.L. High Flood. | R.L. Low Supply. | Difference in Metres. | Discharge. Cubic metres per second. High Flood. | Low Supply. | Remarks |
|---|---|---|---|---|---|---|---|
| Mongalla | 0 | 446·7 | 444·6 | 2·1 | 2000 | 530 | Note how the water of the Albert Nile in flood gradually spreads over the country and the effect of the flood diminishes steadily. |
| | 25 | 440·9 | 438·8 | 2·1 | | | |
| | 75 | 431·8 | 430·3 | 1·5 | | | |
| Bôr | 125 | 422·6 | 421·6 | 1·0 | 900 | 520 | |
| | 175 | 418·6 | 417·6 | 1·0 | | | |
| | 225 | 414·5 | 413·5 | 1·0 | | | |
| Ghaba Shambe | 275 | 410·8 | 409·8 | 1·0 | 480 | 400 | |
| | 325 | 407·0 | 406·1 | 0·9 | | | |
| | 375 | 404·8 | 404·0 | 0·8 | | | |
| Dupuis' Cut | 425 | 402·5 | 402·0 | 0·5 | 340 | 300 | |
| | 475 | 400·3 | 399·8 | 0·5 | | | |
| Hillet Nuêr | 525 | 398·0 | 397·5 | 0·5 | 440 | 400 | |
| | 575 | 395·6 | 395·1 | 0·5 | | | |
| | 625 | 393·2 | 392·7 | 0·5 | | | |
| | 650 | 392·0 | 391·7 | 0·3 | | | |
| Buffalo Cape | 675 | 390·8 | 390·6 | 0·2 | 350 | 350 | Backwater in flood owing to Sobat discharge. |
| | 700 | 390·1 | 389·6 | 0·5 | | | |
| Lake No | 725 | 389·3 | 388·5 | 0·8 | 325 | 350 | |
| Khor Yargol | 750 | 389·0 | 387·8 | 1·2 | | | |
| Attigo | 775 | 388·8 | 387·1 | 1·7 | | | |
| Zeraf tail | 800 | 388·6 | 386·4 | 2·2 | 350 | 330 | |
| Fenikang | 825 | 388·4 | 385·7 | 2·7 | | | |
| Sobat junction | 850 | 388·3 | 385·0 | 3·3 | 500 | 400 | |

TABLE 139.—MONTHLY MEANS OF MONGALLA GAUGE-READINGS (in metres).

| Years. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1902 | 10·97* | 10·91* | 10·94* | 10·71* | 10·89* | 10·64* | 10·80* | 11·52* | 11·29* | 11·22* | 11·47* | 11·32* | 11·057* |
| 1903 | 11·14* | 11·10* | 11·02* | 11·04 | 11·46 | 11·92 | 12 06 | 12·64 | 13·12 | 12·95 | 12·78 | 12·25 | 11·957 |
| 1904 | 12·08 | 11·97 | 11·94 | 12·06 | 12·16 | 12·18 | 12·45 | (12 90) | (12·90) | 12·57 | 12·62 | (12·34) | 12·348 |
| 1905 | 12·10 | 11·94 | 11·78 | 11·81 | 12·14 | 11·87 | 11·93 | 12·09 | 12·52 | 12·20 | 12·49 | 12·43 | 12·108 |
| 1906 | 11·97 | 11·89 | 11·88 | 11·97 | 11·99 | (12·17) | 12·47 | 12·54 | 12·90 | 12·59 | 12·65 | 12·33 | 12·279 |
| 1907 | 12·18 | 12·02 | 11·86 | 11·91 | 12·06 | 12·13 | 12·07 | 12·32 | 12·44 | 12·01 | 12·27 | 11·88 | 12·096 |
| 1908 | 11·66 | 11·48 | 11·38 | 11·32 | 11·43 | 11·53 | 11·77 | 12·34 | 11·84 | 11·62 | 12·24 | 11·64 | 11·688 |
| 1909 | 11·49 | 11·37 | 11·30 | 11·77 | 11·87 | 11·88 | 12·05 | 12·10 | 12·71 | 11·99 | 11·70 | 11·72 | 11·825 |
| 1910 | 11·49 | 11·38 | 11·26 | 11·35 | 11·64 | 11·45 | 11·55 | 12·03 | 12·62 | 12·17 | 12·23 | 11·54 | 11·726 |
| 1911 | 11·28 | 11·12 | 11·05 | 11·10 | 11·26 | 11·26 | 11·44 | 11·49 | 11·75 | 11·70 | 11·72 | 11·44 | 11·384 |
| 1902–11 | 11·64 | 11·52 | 11·44 | 11·50 | 11·69 | 11·70 | 11·86 | 12·20 | 12·41 | 12·10 | 12·22 | 11·89 | 11·85 |
| 1903–11 | 11·71 | 11·59 | 11·50 | 11·59 | 11·78 | 11·82 | 11·98 | 12·27 | 12·53 | 12·20 | 12·30 | 11·95 | 11·95 |

*Note.*—Readings taken on the temporary gauges have all been brought into line with those taken on the masonry gauge used since June 1905.

TABLE 140.—MONGALLA MEAN DISCHARGE (in cubic metres per second).

| Years. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1902 | 576* | 558* | 567* | 502* | 552* | 485* | 525* | 806* | 696* | 668* | 780* | 709* | 619* |
| 1903 | 636* | 620* | 592* | 599 | 775 | 1044 | 1157 | 1708 | 2164 | 2002 | 1841 | 1338 | 1206 |
| 1904 | 1178 | 1079 | 1058 | 1157 | 1252 | 1271 | 1528 | 1955 | 1955 | 1642 | 1689 | 1423 | 1432 |
| 1905 | 1195 | 1058 | 953 | 971 | 1233 | 1010 | 1051 | 1186 | 1595 | 1290 | 1566 | 1509 | 1218 |
| 1906 | 1079 | 1023 | 1017 | 1079 | 1093 | 1262 | 1547 | 1614 | 1955 | 1661 | 1718 | 1414 | 1372 |
| 1907 | 1271 | 1119 | 1004 | 1037 | 1157 | 1224 | 1167 | 1404 | 1518 | 1110 | 1357 | 1017 | 1199 |
| 1908 | 881 | 785 | 736 | 709 | 760 | 810 | 947 | 1423 | 991 | 857 | 1328 | 870 | 925 |
| 1909 | 790 | 731 | 700 | 917 | 1010 | 1017 | 1148 | 1195 | 1775 | 1093 | 905 | 917 | 1016 |
| 1910 | 790 | 736 | 684 | 722 | 870 | 770 | 820 | 1129 | 1689 | 1262 | 1319 | 815 | 967 |
| 1911 | 692 | 628 | 602 | 620 | 684 | 684 | 765 | 790 | 935 | 905 | 917 | 765 | 749 |
| Mean, 1902–11 | 909 | 834 | 791 | 831 | 939 | 958 | 1066 | 1321 | 1527 | 1249 | 1342 | 1078 | 1070 |

* Mongalla inferred from Gondokoro.

If there were no Sobat flood, from Buffalo Cape onwards the flood and summer discharges and levels would have been the same from Buffalo Cape to the Zeraf mouth.

33. **The Bahr Zeraf, or Giraffe River,** is the right-hand branch of the Albert Nile, which now leaves the latter river north of Ghaba Shambe at the new cut made by Mr Dupuis in 1910. Beginning as a drainage khor of the Lower Albert Nile, it is probable that the Bahr Zeraf has cut its way back towards the Upper Albert Nile till it trapped some of the overflow from the latter in flood, and in course of time there is little doubt but that the river would have itself accomplished what engineering has now done for it. As originally dredged, Dupuis' cut was 15 metres wide, side slopes 1 in 1, and R.L. of bed 391·50 metres. The natural channel is 40 metres wide and 2·5 metres deep at its head, and after a tortuous course of 290 kilometres tails into the Albert Nile 80 kilometres below Lake No. In its lower reaches it is 50 to 60 metres wide, and from 2 to 4 metres deep in the low stage and 6 to 8 metres deep in flood. Its discharges vary from 70 cubic metres per second in low stage to 200 cubic metres in high flood. Of the former some 50 cubic metres are due to the opening of the new channel. In this length of 290 kilometres the river falls 14 metres in flood and 16 metres in low supply, but the fall is very unevenly distributed. From the Albert Nile down Dupuis' cut to the natural channel is a length of 4 kilometres in which the fall in summer is 1 metre and the water courses down like a mill-race. In flood, when the whole country is inundated, the fall is normal. In the 286 kilometres down the natural channel the first half has a fall of 10·5 metres and the lower half 4·5, making with the metre drop in the first kilometre the 16 metres. The Zeraf River for its first 90 kilometres is a winding trench without banks, flowing between vast plains of tall grass at first, and low grass later with dom-palms scattered about here and there. In low supply, when the river is discharging 70 cubic metres per second, it is within its trough, but in flood, when the country is under water, its section is not large enough to draw off the supplies while the Sobat is throwing back water on it. At kilometre 5 Baker's cut flows in. This historic piece of water was dredged and cleared in 1912. At kilometre 54 a drainage channel some 60 metres wide flows in from the south, and shortly afterwards the Zeraf becomes a trough in a valley, not clearly marked at first, but gradually becoming more and more marked until midway down the course of the river the valley through which the trough is cut is itself 2 metres below the normal level of the country. The valley dies out and disappears altogether near the tail. The general width of the valley may be taken as half a kilometre. Through this higher ground numerous drainage channels, bringing down the rainfall from the south and overflows from the Albert Nile on the west, cut their way and add their

The Albert Nile, Hillet Nuêr.

The Albert Nile, Lake No.

The Bahr el Zeraf (Grass).

Gazelle River, Mouth of River Rohl.

contributions to the Zeraf, whose section increases steadily as one advances northwards.

In the last 200 kilometres of its course the Zeraf flows through a plain covered with low grasses, which are burnt in winter. Acacias are met with nearly everywhere. There is no papyrus on the Zeraf, as the soil traversed by it is the natural hard soil of this part of Africa and the papyrus only grows on the fresh deposits of decayed vegetation of the Albert Nile, *i.e.* in its delta.

Dupuis' cut was excavated 15 metres wide and 5 metres deep and discharged 50 cubic metres per second two years ago, but it has scoured out its bed and sides and is now capable of discharging 80 cubic metres per second.

TABLE 141.—ZERAF RIVER.

| Distance from Head in kilometres. | R.L. of High Flood in metres. | R.L. of Low Supply in metres. | R.L. of Ground. | R.L. of Lowest Point of Bed. | Remarks. |
|---|---|---|---|---|---|
| 0 | 402·8 | 402·3 | 402·2 | ... | Head of Dupuis' cut. |
| 4 | 402·6 | 401·3 | 400·8 | ... | Tail of Dupuis' cut. |
| 20 | 401·3 | 400·3 | 400·0 | 396·1 | Zeraf proper. |
| 40 | 399·7 | 398·3 | 398·6 | 393·7 | |
| 60 | 398·4 | 396·4 | 396·8 | 393·6 | |
| 80 | 397·4 | 395·0 | 396·1 | 392·6 | |
| 100 | 396·4 | 393·6 | 395·6 | 391·4 | |
| 120 | 395·2 | 392·3 | 394·1 | 389·8 | |
| 140 | 394·3 | 391·0 | 393·6 | 392·1 | |
| 160 | 393·5 | 390·2 | 392·9 | 386·0 | |
| 180 | 392·8 | 389·4 | 392·1 | 384·7 | |
| 200 | 392·1 | 388·7 | 391·8 | 384·3 | |
| 220 | 391·4 | 388·0 | 391·4 | 383·9 | |
| 240 | 390·7 | 387·4 | 389·7 | 382·6 | |
| 260 | 389·9 | 387·0 | 389·4 | 382·1 | |
| 280 | 389·0 | 386·6 | 388·7 | 380·9 | |
| 290 | 388·5 | 386·4 | 388·6 | 381·1 | Tail. |

The mean discharge of the Zeraf is 140 cubic metres per second. With a very moderate amount of dredging work, this river could discharge 160 cubic metres per second without wasting much water. While carrying this discharge it might flood an additional 350 square kilometres of swamp which, with an evaporation of 9 millimetres per day from January to May, would entail a loss of 40 cubic metres per second. The quota of the low-supply overflows of the Awai and Atem, as measured, is some 30 cubic metres per second, so that if the Dupuis' cut discharged 160 cubic metres per second, we might expect 150 cubic metres per second at the tail. The

importance of the Zeraf lies in its being at a lower level than the Albert Nile and in its avoiding altogether the Gazelle swamps. We agree with those who hold that if 160 cubic metres were withdrawn from the Albert Nile by Dupuis' cut the discharge of the Albert Nile at Lake No would not be seriously affected, as more water would immediately flow into it from the surrounding swamps, or less be wasted in them.

We give some interesting levels down the Zeraf (Table 141). It will readily be seen that the discharging capacity of the river in its last 150 kilometres is very great when the Albert Nile in its tail reach is not thrown into a severe backwater by the Sobat flood. From January to May this river has a fine carrying channel, which is available the moment Dupuis' cut is capable of discharging two or three times what it discharges to-day.

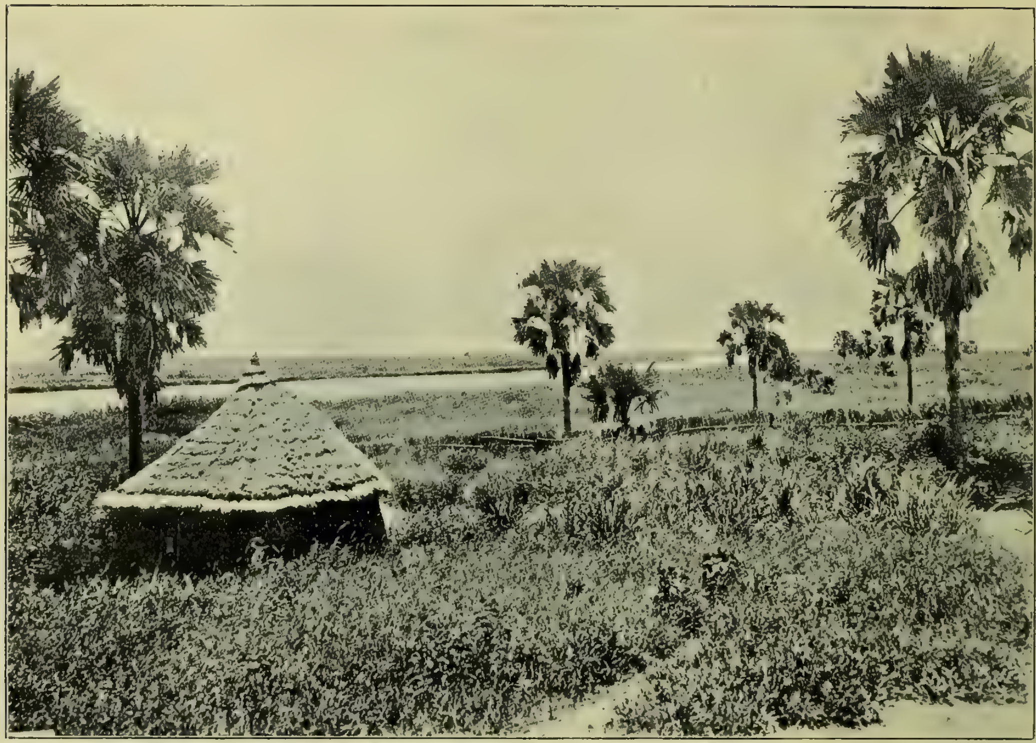
34. **The Bahr Ghazal, or the Gazelle River,** which flows into the Albert Nile at Lake No, has an effective catchment basin of 370,000 square kilometres and a mean annual rainfall of 335 cubic kilometres. Lake No and the swampy, marshy ground around it cover a vast area, of whose interior no one knows anything. Into this marshy, swampy basin pour the Gazelle and all its tributaries: the Nam-Rohl, the Jur, Jau, Wau, Tonj, Bongo, Mohmal, Lol, and Bahr el Arab [we follow Captain Lyons' spelling]. These rivers in flood pour immense quantities of water into this depression, which, moreover, has already been credited with absorbing some 80 cubic metres per second of Albert water in addition to all its own water. The Albert Nile actually loses 100 cubic metres per second, but gets back 20, so that the net loss is 80. All these waters are lost by evaporation. Now, the mean effective rainfall is 335,000 million cubic metres, of which $\frac{1}{15}$th or 22,500 millions of cubic metres may be considered as entering the swamp. To this has to be added the 80 cubic metres per second of the Albert discharge, or 2500 millions per annum. The total quantity of water lost must be near 25,000 million cubic metres, or 800 cubic metres per second. As the mean annual discharge of the Albert Nile is only 350 cubic metres per second, the Gazelle River with its supplies performs the useful function of, year in year out, keeping these swamps full of water.

As the evaporation of this region is about 2·4 metres per annum, and the quantity evaporated is 25,000 million cubic metres, the average area of the swamp works out to about 10,000 square kilometres.

The real discharge from Lake No into the Albert Nile can only be measured by comparing the discharge of the Albert Nile entering Lake No with that leaving it and crediting the Gazelle with the difference. On occasions the difference has been 80 cubic metres per second, but the comparison has unfortunately been rarely made. On the 6th July 1912 the difference was 25 cubic metres per second, but the Sobat had begun to throw back water on Lake No. The measured discharges of the

The Gazelle River (Bahr el Ghazal).

The Gazelle River blocked by Grass Sudd.



The Sobat River from Doleib Hill.

The Sobat River near the Tail.

Gazelle have varied from 10 to 40 cubic metres per second, but these discharges are no real measure of the water supplied by Lake No.

The width of the Gazelle may be taken as varying between 40 and 80 metres, and its depth between 5 and 7 metres. With its velocities, sections, and discharges, the slope works out to $\frac{1}{500,000}$, but on a levelled length of 25 kilometres where it could be levelled, the slope came to $\frac{1}{25,000}$. Weeds account for much.

The Gazelle has a greater retardation of its discharge than the Sobat. Here are some gauges which show that the water which passes Wau attains its maximum in September, while at Meshra el Rek, a few kilometres lower, it is not attained till the end of December.

When the Sobat throws back water on Lake No, this backwater apparently goes well beyond Lake Ambadi on the Gazelle and may even affect Meshra.

The Gazelle River has no papyrus, and its sudds are formed of grasses and weeds. It has been badly sudded at times, owing probably to excessive backwaters of the Sobat and the Albert Nile.

TABLE 142.—GAUGES ROUND LAKE NO.

| Date. | Gazelle River. | | Albert Nile. | | Sobat. | White Nile. | |
|---|---|---|---|---|---|---|---|
| | Wau. | Meshra. | No. | Attigo. | Doleib Hill. | Malakal. | |
| **1909.** | | | | | | | |
| March 24 | .. | 2·19 | 1·54 | −0·17 | −0·64 | −2·08 | |
| April 14 | ... | 1·66 | 1·55 | −0·16 | −0·24 | −1·76 | |
| 28 | ... | 1·36 | 1·57 | −0·11 | −0·23 | −1·72 | |
| May 14 | ... | 1·06 | 1·55 | −0·13 | −0·10 | −1·57 | |
| 18 | ... | 1·08 | 1·57 | −0·14 | −0·07 | −1·56 | |
| June 16 | 1·07 | 1·06 | 1·63 | 0·02 | 0·53 | −1·04 | |
| July 15 | 1·12 | 1·10 | ... | 0·34 | 1·96 | −0·66 | |
| August 15 | 2·93 | 1·52 | ... | 0·67 | 1·53 | −0·16 | |
| September 15 | **3·64** | 1·76 | ... | 1·12 | 2·13 | 0·40 | |
| October 15 | 3·34 | 2·04 | ... | **1·46** | **2·52** | **0·77** | |
| November 15 | 1·68 | 2·03 | **2·11** | 1·33 | 2·39 | 0·61 | |
| December 18 | 0·56 | **2·05** | 2·07 | 1·24 | 2·35 | 0·56 | |
| **1910.** | | | | | | | |
| January 13 | ... | 2·02 | 2·01 | 1·16 | 2·17 | 0·47 | Max. Meshra 2·06 1st January. |
| February 15 | ... | 1·89 | ... | 0·38 | −0·38 | −0·96 | |
| March 20 | ... | 1·71 | 1·60 | −0·10 | −0·53 | −1·79 | |
| | | | To find true R.L. of water add 387·0 metres to these figures. | | | | |

If it were not for the hippopotami, the "Singara" or Indian water nut might be introduced here with great advantage to the inhabitants.

35. **The Sobat River.**—This river drains 154,000 square kilometres lying between the catchment basins of Lake Rudolf, the Blue Nile, and the Albert Nile, but it is likely that some 16,000 square kilometres of this area are ineffective. The rainfall of the basin amounts to 150 cubic kilometres, equivalent to a uniform fall of 1·09 metres per annum over the effective area. The rainfall in the mountainous region of Gallaland is plentiful and especially heavy in autumn, and were it not for the extensive lakes and marshes in its middle course, the Sobat would be a torrent in flood. Regulated and restrained by the lakes and marshes, this river has an extraordinarily even rise and fall, as a reference to Table 77 will certify. The discharges vary from 40 cubic metres per second in low supply to 1000 cubic metres in flood, though there have been years when the discharges have fallen to zero in summer and when the flood must have exceeded 1500 cubic metres per second. April is the month of low supply and November of maximum flood, partly in consequence of the delay caused by the filling of the marshes, and partly owing to the heavy autumn rainfall in the southern portion of the basin.

In its last 50 kilometres the river has a deep, well-defined channel between banks, which are never topped in the highest floods. The width of waterway is about 110 metres, and the depth 7 metres in summer and about 10 to 11 metres in flood.

The principal tributaries of the Sobat are the Baro from the north-east and east, and Pibor from the south-east and south.

The Baro is a mountain torrent draining the southern flanks of the Wallega mountains, from which the Didessa and Yabus tributaries of the Blue Nile receive their water. Consequently it is not uncommon to find flushes due to the same rainfall affecting simultaneously the Baro and the Blue Nile. All the tributaries meet and form extensive swamps from which the Sobat has its origin. The village of Nasser is situated on the Sobat near the junction of the Baro and Pibor. A gauge has been erected here, but unfortunately has been read very interruptedly.

The Pibor is formed from a number of tributaries, the chief of which are the Akobo and Agwei. It was explored in August 1904 by Lieutenant Comyn,* who met with a good deal of thin sudd. The Agwei ran between high banks some 65 metres apart, was 6 metres deep, and had a velocity of about 1 metre per second. This would give a discharge of some 200 to 250 cubic metres per second. One portion of the course was flooded. The Akobo rises in the hills to the west of Lake Rudolf, in latitude 6° N., and joins the Pibor to the south of the Agwei. All of these rivers are much affected by the autumn rains, which are heavy on this ridge. North of the junction the Pibor is a broad stream with banks some 100 to 700 metres apart, but to the south it contracts to a width of 100 to 200 metres. At a

* *Geog. Jour.*, xxxi., 1908, p. 304.

point 120 kilometres south of the Agwei the width is only 30 metres, and the depth about 6, but the current has risen to 2 metres per second. This would give a discharge of about 200 to 240 cubic metres per second. Several flooded plains were encountered in the upper reaches. The river was found by Major Darley * to rise in about latitude 4°.

It is possible that a low regulator near the junction of the Baro and Pibor would hold up an enormous quantity of water.

The Doleib Hill gauge is in the backwater of the Albert Nile and is not very reliable. A regular gauge far enough up the river to be out of this backwater is a great desideratum.

The Khor Filus, draining the rainfall of the plains between the Zeraf and the Sobat, flows into the Sobat a few kilometres above its tail.

The discharges of the Sobat have in recent years been very carefully measured. Paragraph 27 of CHAPTER II. gives full information about them.

From the point where the Albert Nile and Sobat meet starts the White Nile.

Flowing eastwards in a wide channel, some 400 metres wide and 3 metres deep, with a gentle slope, and low shelving banks easily capable of being overflowed, the Albert Nile meets the Sobat River and turns abruptly northwards. The Albert Nile contains peat-coloured water, free of deposit, through the twelve months of the year. The Sobat in flood does not carry much deposit to speak of, but it carries more than the other.

Now the Albert Nile just upstream of the Sobat junction is at its lowest in April and May, so is also the Sobat. Both rivers begin to rise together, and we have one of the most interesting operations of any in the whole valley of the Nile, exceeded only in interest by what happens at Khartoum lower down. The Albert Nile can easily overflow its banks, while the Sobat is confined to its channel. Downstream of the junction the White Nile has little carrying capacity and is incapable of taking on both floods. The water rises at the junction and overflows the whole low-lying country. While the Sobat, confined to its channel, gradually increases its discharge from about 50 cubic metres per second in April to 1000 cubic metres in November, the Albert Nile, upstream of the Sobat, actually decreases the discharge it sends northwards and increases what it spreads over the country. These impounded waters which have spread over the country form a temporary lake, and gradually pass on in December, January, and February, when the Sobat has fallen. Here is another great natural reservoir of the Nile capable of being utilised.

Table 114 of paragraph 27 of CHAPTER II. shows this action very clearly.

36. **The Sudd Region.**—The Sudd region of the Albert Nile lies north

* *Geog. Jour.*, xxxvii., 1911, p. 214.

of Ghaba Shambe, and corresponds to that part of the river where not only do the floods overflow the banks but the summer supplies generally do so. It is the region of papyrus, which only flourishes on the fresh deposit of the Albert Nile or in the true delta of the river where the sandy deposit is mixed largely with vegetable detritus.

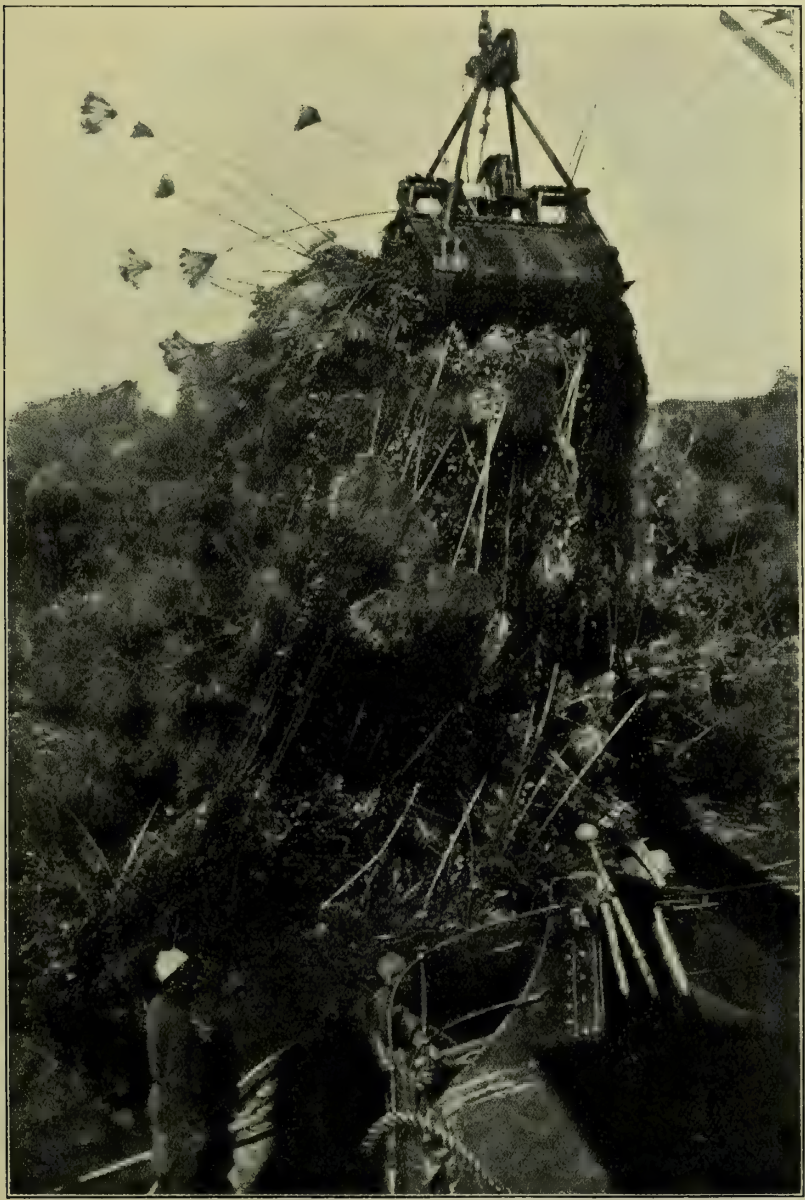
There are two main branches to the river, the Albert Nile proper and the Zeraf, which have both been already described. Both these rivers are liable to be blocked by sudd or blocks of living vegetation. These blocks are sometimes as much as 5 metres thick and capable of turning nearly the whole supply of the river out of its course. They are formed of water-grasses, papyrus, and weeds, which grow along the banks of the rivers and the marshes traversed by them, and which, under the double action of a rising flood and strong winds, are torn up and driven into the channels wherever they are confined in width, and there jammed into solid masses filling the whole width of the river, very nearly the whole depth, and sometimes over a kilometre in length. Worse even than the papyrus is the water-grass, or "um soof," which is as full of life when floating in water as it is when fixed to the earth. Every time a bank is undermined and falls in or a hippopotamus walks out of the river, masses of these grasses are sent floating downstream, ready to take root wherever they stick.

While the sudd floats, it is not so bad as when it sinks, as it did at block No. 15, south of Hillet Nuêr, where the Nile left its course for 40 kilometres owing to sunken sudd.

The Sudd region is unmistakably, as Lombardini pointed out years ago, an old lake which has silted up and become full of decayed vegetation and sand deposits. At one time the lake must have had an extreme length of 400 kilometres and width of 200 kilometres. The Sobat River flowed into it, and the escape waters of the Blue Nile may have flowed backwards up the bed of the present While Nile before the Shabluka gorge was pierced.

The dense masses of papyrus and water-grasses which shut out the horizon in every direction intimidated the expedition sent up the Nile by Nero, and it returned northwards without having accomplished anything. From Nero's time to that of Mehemet Ali little was known of these regions. Mehemet Ali made a determined effort to discover what lay beyond these inhospitable regions, and sent up a well-equipped expedition under D'Arnaud.

One of the earliest descriptions of the Nile between the fifth and tenth parallels of latitude is by Werne, who accompanied D'Arnaud's expedition to the Upper Nile in 1840–1841. The expedition found the channel of the White Nile and Albert Nile easily navigable between December and March. The Albert Nile between 7° and 9° N. lat. had apparently a mean width of 120 metres, depth of 5 metres, and velocity of about 60 centimetres per second, giving a discharge of some 400 cubic metres per



Grab Dredger in the Sudd Region.

Sudd Region Papyrus.

second. In this first description of the river the fact that strikes one most forcibly is the omission of the Bahr Zeraf. Neither the inlet nor the outlet are mentioned, though the Sobat, the Gazelle, and numerous insignificant streams are minutely recorded. Practically the whole of the water was confined to one stream, and that a good one. The water-level in winter was found to be some 50 centimetres below the general level of the berm, and about 60 centimetres above this level in flood. Between the river and the swamps in its southern reaches were numerous cuts and openings, some natural and some artificial, made by the aborigines for fishing purposes. While traversing the swamps, the waters of the river in flood lost their silt and became quite clear. On p. 100 of vol. ii. of Werne's work there is this sentence: "The report that the natives below (*i.e.* in latitude 5° to 7°) had blocked the river to cut off our retreat, turned out to be unfounded." From the above it will be noticed that the aborigines in 1840–1841 spoke of their ability to block the course of the river, while the training works in the side channels and spills for fishing purposes were described as solid works regulated by rows of strong stakes driven into the ground.

Between 1841 and 1863 the expeditions up the Nile considerably increased, while the aborigines were being brutally treated by the slave-traders. What could be more natural than that, as a measure of protection, the aborigines should have widened and deepened the side channels and spills which took off from the river between latitudes $5\frac{1}{2}°$ and $7\frac{1}{2}°$, so that they might escape from the traders? Subsequently, when the main river was patrolled by Government boats, the slave-traders themselves used these side channels for prosecuting their traffic. All the channels and spills on the right bank of the Albert Nile tailed into the Bahr Zeraf, which now began to form an appreciable stream, and which was navigated over the lower part of its course by Petherick between 1853 and 1862. The Bahr Zeraf was, however, always described as sudded, while the Albert Nile was open to navigation. This action of dissipating the waters of the river went on increasing till 1863, when there occurred a very high flood indeed; the waters escaped everywhere from the main stream, while the floating masses of grasses and weeds were confined to the main channel and sudded it downstream of Lake No.

On ascending the White Nile and Albert Nile in January 1863, Sir Samuel Baker found the passage clear to the south. On returning in April 1865, he found the sudd of the flood of 1863 still in the Albert Nile downstream of Lake No. The sudd was 1000 metres long and had a passage 3 metres wide cut through the middle of it, down which the river ran like a mill-race.

In February 1869 Dr Schweinfurth and his party, on their way to the Gazelle, took six days to get through this sudd, though the main

obstruction was now only 200 metres long. In July 1872 Dr Schweinfurth on his way back found the sudd to the downstream of Lake No as before, and described the opening through it as "a narrow stream of water which rushed along as a wild brook. The depth of the fairway varied from 2 to 3 metres, and the boat nowhere touched the bottom."

In February 1870 Sir Samuel Baker found the sudd in the Albert Nile impassable for his expedition of heavily laden boats and steamers. He found the Zeraf sudded in its southern 100 kilometres, and tried to cut his way through, but failed. And yet the slave-traders had means of getting slave-boats down the Bahr Zeraf (*Ismailia*, pp. 61, 62, and 29). Baker returned in January 1871 to the Zeriba Kutchuk Ali on the Bahr Zeraf, and had before him the 100 kilometres of sudded channel. With the aid of 1200 men he completed the work by 13th March. The final operation was a canal through stiff clay 600 metres long (known to-day as Baker's cut). The fall from the Albert Nile into the Bahr Zeraf was so great (we have seen that it is 1 metre) that, in order to get the boats and steamers across the final distance, Baker made a dam 120 metres long across the Zeraf by means of a double row of piles, sand bags, and fascines of the tall grasses. He thus secured the necessary depth of water, and the flotilla sailed into the Albert Nile. On his way back in June 1873, he thus describes the appearance of the head of the Zeraf river where he had made the cut in March 1871:—

"On arrival at the Bahr Zeraf cut, we found that the canals which we had formerly cut were much improved by the force of the stream. Although these passages were narrow, they had become deep, and we progressed with comparatively little trouble." The rest of the journey down the Bahr Zeraf was easily performed.

In January 1874, when the river was low, the sudd in the Albert Nile was removed by Ismail Pasha Ayoub, Governor-General of the Sudan.

From 1874 to 1878, while Gordon was Governor-General, the Albert Nile was clear of sudd, but the wide stream of 1840 had dwindled down to a clear waterway free of weeds on a width of only 6 metres in one place, and from 20 to 30 metres over long reaches. This is clearly recorded on the map prepared by General Gordon and his staff in 1874 to 1877. The escape of water down numerous spills had deprived the Albert Nile of the power of keeping its channel clear, and when the heavy flood of 1878 came down the river was sudded.

In 1880 Gessi was blocked in the Bahr Ghazal. The sudd in this Bahr was cut by Marno, who also cut the sudd in the Albert Nile in April 1880.

Emin Pasha mentions the fact that the Albert Nile was free of sudd and navigated from 1880 to 1883. In 1884 he states that no steamers reached Lado, but he attributed that to the Mahdi's rebellion.


FIG. 19.—The Albert Nile from Gondokoro to the Sobat Junction (1903), showing Sudd Blocks.

During the early years of the Mahdi's and Khalifa's rule there was no sudd. In the Khalifa's time a boat laden with ivory sank in the stream where sudd block No. 15 is, south of Hillet el Nuêr, and caused the block to form.

In 1898 Lord Kitchener found the Albert Nile sudded south of Lake No, and in March 1899 Sparkes Bey, of the Egyptian Army, steamed up the Bahr Zeraf to within 30 kilometres of its head.

At the same time Sir William Garstin thought the Bahr Zeraf a stronger stream than the Albert Nile.

Descending the Albert Nile from Uganda, Colonel Martyr found the Albert Nile sudded 30 kilometres north of Ghaba Shambe.

In 1900 and 1901 Major Peake, C.M.G., R.A., and Lieutenant Drury, R.N., removed sudd blocks Nos. 1 to 14, and 16 to 19, between Lake No and Ghaba Shambe. There now remained only block No. 15 south of Hillet el Nuêr, which was removed in 1904.

The condition of the channel to-day has been described under the heading of the "Albert Nile."

The channel to-day is a very fine channel, generally from 75 to 120 metres wide and 5 or 6 metres deep. Comparing sections made in 1903 with those made in 1911 and 1912 in the decayed vegetable soil, we may say that the river has not deepened its channel much, but has widened it by 10 to 15 metres even where it was wide, while where it was narrow it has widened it out of recognition. Where in 1906 one's steamer touched both banks in places in the channel south of Hillet Nuêr, to-day the width is from 50 to 60 metres.

This action of widening is going on, and if it were considered advisable to widen and deepen the channel of the Albert Nile it might, we think, be only necessary to harrow up the bed of the river, and the strong stream of clear water would do the rest.

We give a series of cross sections taken in 1912 by Mr E. M. Tabor, for Mr P. M. Tottenham, of the Albert Nile from Lake No upstream to within some 10 kilometres of Hillet el Nuêr. They show how readily the river overflows its banks in low supply.

The Sudd region stores an enormous quantity of water, though much of it is wasted to-day. It is for engineers to consider how it can be utilised. The following table gives the approximate area over which the water is spread and the quantity which is spread. We leave out the 140 cubic metres per second which pass down the Zeraf and 80 cubic metres per second which are lost in the swamps of which Lake No is the lowest point. These 220 cubic metres per second in all are outside this calculation. The mean discharge at Mongalla is 1070 cubic metres per second, and of the Albert Nile into Lake No is 350. The quantity to be accounted for is (1070 − 350 − 220, or) 500 cubic metres per second.

TABLE 143.—OVERFLOW OF THE ALBERT NILE PROPER BETWEEN MONGALLA AND LAKE NO.

| Locality. | Length along the River, in kilometres | Direct Length, in kilometres. | Mean Width of Overflow, in kilometres. | Depth of Flooding, in metres. | Area flooded, in millions of square metres | Contents of the Flooding, in millions of cubic metres. |
|---|---|---|---|---|---|---|
| Mongalla to Bôr . . | 125 | 100 | 10 | 3·0 | 1000 | 3,000 |
| Bôr to Ghaba Shambe . | 183 | 160 | 20 | 1·5 | 3200 | 4,800 |
| Shambe to Hillet Nuêr . | 194 | 130 | 20 | 1·0 | 2600 | 2,600 |
| Hillet Nuêr to Lake No* | 225 | 160 | 5 | 0·5 | 800 | 400 |
| Total . . | 727 | 550 | ... | ... | 7600 | 10,800 |

* Right bank only.

A cubic content of 10,800 million cubic metres means a discharge of 340 cubic metres per second for twelve months, or 680 cubic metres per second for six months. As the Mongalla-No basin is being filled for six months, and drawn on for six months, the Albert Nile pours into this Sudd region 680 cubic metres per second for six months, which is all evaporated.

The other factors are the following:—

The area of overflow is 7600 square kilometres, and from paragraph 11 the evaporation is 6·6 millimetres per day, or 2·4 metres per annum. The rainfall on the above area is only 0·9 metre per annum. The catchment basin of this region independent of the Zeraf River is 80,000 square kilometres, and from paragraph 23 we see that about one-fifteenth of the rainfall reaches the Albert Nile.

Therefore the evaporation amounts to 580 cubic metres per second; the rainfall to 210 cubic metres per second; the supply of the tributaries to 150 cubic metres per second; and we have seen that the Albert Nile brings into this reach more than it takes out—500 cubic metres per second.

The total assets are 500+210+150=860 cubic metres per second, and the loss amounts to 580, leaving 280 cubic metres per second to be absorbed into the ground or by plants.

The evaporation and plant absorption items are so heavy that the only way to secure more water from this reach of the Nile is to widen and deepen the channels which take off the water and so reduce the water-level of the swamped area and with it the losses by evaporation. This is returned to in CHAPTER XII.

Downstream of Lake No, in the No-Malakal reach, the volume stored between low and high supply is 1500 million cubic metres, or 50 cubic metres per second for twelve months, or 200 cubic metres per second for three months. This is supplied in three months and drawn off in three months. Most of this water finds its way into the White Nile when the Sobat begins to fall.

TABLE 144.—THE ALBERT NILE: LAKE NO TO HILLET NUÊR (in metres).
(To refer these R.L.'s to those in the book, add 7·10 metres to each.)

| Kilometres from Lake No. | L.S.W.L. | Area at L.S.W.L. | Width, Open Water. | Deepest Point in Bed. | Mean Bed-level. | Ground Level 10 metres from Edge of Papyrus. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Right. | Left. |
| 1·0 | 381·26 | 438 | 77 | 374·74 | 375·35 | 379·70 | 381·50 |
| 2·1 | 381·30 | 538 | 103 | 373·38 | 376·08 | 381·90 | 381·00 |
| 3·1 | 381·34 | 508 | 80½ | 374·03 | 375·04 | 380·10 | 380·40 |
| 4·5 | 381·40 | 473 | 77 | 374·09 | 375·25 | 380·60 | 380·80 |
| 5·6 | 381·44 | 482 | 83 | 374·48 | 375·63 | 379·80 | 381·00 |
| 6·5 | 381·48 | 482 | 75 | 374·32 | 375·04 | 380·40 | 381·10 |
| 7·3 | 381·51 | 458 | 70 | 373·01 | 374·96 | 381·10 | 380·80 |
| 8·0 | 381·54 | 409 | 72 | 374·78 | 375·86 | 381·35 | 380·95 |
| 9·0 | 381·58 | 489 | 76½ | 373·87 | 375·19 | 381·00 | 380·25 |
| 10·0 | 381·62 | 486 | 77 | 374·34 | 375·31 | 381·25 | 380·60 |
| 11·0 | 381·66 | 484 | 89 | 375·23 | 376·22 | 380·35 | 381·90 |
| 12·0 | 381·70 | 436 | 93 | 376·44 | 377·02 | 380·60 | 382·00 |
| 13·0 | 381·74 | 467 | 75½ | 374·88 | 375·56 | 381·30 | 380·95 |
| 14·0 | 381·78 | 436 | 69½ | 373·92 | 375·53 | 382·10 | 381·35 |
| 15·0 | 381·82 | 464 | 82½ | 374·76 | 376·22 | 381·80 | 381·10 |
| 15·9 | 381·86 | 411 | 92 | 376·27 | 377·41 | 380·50 | 381·90 |
| 17·0 | 381·90 | 444 | 79½ | 375·75 | 376·30 | 380·80 | 380·80 |
| 18·0 | 381·94 | 467 | 75½ | 373·84 | 375·76 | 381·60 | 381·10 |
| 19·0 | 381·98 | 466 | 79½ | 375·28 | 376·12 | 381·65 | 381·10 |
| 20·0 | 382·02 | 442 | 78 | 375·57 | 376·34 | 381·40 | 381·40 |
| 21·0 | 382·06 | 424 | 89 | 376·66 | 377·30 | 381·45 | 380·70 |
| 22·0 | 382·10 | 453 | 76 | 375·50 | 376·11 | 380·80 | 381·20 |
| 23·0 | 382·14 | 412 | 74 | 375·84 | 376·58 | 382·40 | 381·40 |
| 24·0 | 382·18 | 438 | 76 | 375·18 | 376·41 | 381·25 | 381·85 |
| 25·0 | 382·22 | 415 | 81½ | 376·57 | 377·13 | 381·95 | 381·10 |
| 26·3 | 382·27 | 424 | 65 | 374·03 | 375·74 | 382·10 | 380·45 |
| 27·2 | 382·31 | 434 | 86 | 375·99 | 377·26 | 382·20 | 381·20 |
| 28·0 | 382·34 | 439 | 96 | 376·90 | 377·77 | 381·30 | 381·50 |
| 29·0 | 382·38 | 470 | 84 | 376·24 | 376·79 | 381·35 | 381·65 |
| 30·0 | 382·42 | 379 | 78 | 376·80 | 377·56 | 380·95 | 381·70 |
| 31·0 | 382·46 | 383 | 80½ | 377·17 | 377·66 | 381·65 | 382·00 |
| 32·0 | 382·50 | 457 | 87½ | 377·01 | 377·28 | 381·55 | 381·50 |
| 33·0 | 382·54 | 482 | 95 | 377·00 | 377·46 | 381·70 | 381·60 |
| 34·0 | 382·58 | 406 | 77½ | 376·99 | 377·34 | 381·65 | 381·55 |
| 35·0 | 382·62 | 413 | 76½ | 376·19 | 377·23 | 381·65 | 381·90 |
| 36·0 | 382·66 | 467 | 92½ | 376·83 | 377·62 | 381·20 | 381·10 |
| 37·0 | 382·70 | 469 | 89 | 376·77 | 377·43 | 381·67 | 381·62 |
| 38·0 | 382·74 | 436 | 76 | 376·06 | 377·00 | 381·90 | 381·70 |
| 40·0 | 382·82 | 483 | 84 | 377·14 | 377·42 | 382·06 | 381·36 |
| 41·0 | 382·86 | 465 | 86½ | 376·94 | 377·48 | 381·80 | 381·70 |
| 42·0 | 382·90 | 487 | 97 | 377·58 | 377·87 | 381·70 | 381·80 |
| 43·0 | 382·94 | 488 | 77½ | 376·17 | 376·96 | 381·80 | 381·90 |
| 44·0 | 382·98 | 496 | 87½ | 376·76 | 377·31 | 382·30 | 382·50 |

TABLE 144.—*continued.*

| Kilometres from Lake No. | L.S.W.L. | Area at L.S.W.L. | Width, Open Water. | Deepest Point in Bed. | Mean Bed-level. | Ground Level 10 metres from Edge of Papyrus. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Right. | Left. |
| 45·0 | 383·02 | 494 | 77½ | 375·80 | 376·64 | 382·20 | 382·05 |
| 46·0 | 383·06 | 443 | 79 | 376·24 | 376·95 | 382·15 | 381·70 |
| 46·8 | 383·10 | 426 | 81 | 377·19 | 377·85 | 382·20 | 382·35 |
| 48·0 | 383·14 | 486 | 79 | 376·52 | 376·99 | 382·35 | 381 80 |
| 49·0 | 383·18 | 442 | 72½ | 375·56 | 377·08 | 382·60 | 381·95 |
| 49·7 * | 383·21 | 432 | 82½ | 376·79 | 377·97 | 383·15 | 381·80 |
| 51·1 | 383·26 | 509 | 86 | 376·99 | 377·34 | 382·14 | 382·59 |
| 52·1 | 383·30 | 468 | 71 | 375·88 | 376·73 | 382·53 | 382·23 |
| 53·1 | 383·34 | 446 | 80 | 376·67 | 377·46 | 382·67 | 382·07 |
| 54·1 | 383·38 | 522 | 93 | 377·26 | 377·76 | 382·22 | 382·32 |
| 55·1 | 383·42 | 423 | 82 | 377·45 | 378·25 | 382·57 | 382·66 |
| 56·1 | 383·46 | 479 | 75 | 376·19 | 377·09 | 382·36 | 382·01 |
| 57·6 | 383·52 | 445 | 80 | 376·73 | 378·48 | 381·63 | 381·53 |
| 58·0 | 383·65 | 510 | 95 | 377·67 | 378·20 | 382·67 | 382·17 |
| 59·0 | 383·60 | 527 | 138 | 374·11 | 379·77 | 382·51 | 383·01 |
| 60·0 | 383·64 | 523 | 103 | 377·95 | 378·55 | 382·22 | 382·16 |
| 61·0 | 383·68 | 427 | 80 | 377·59 | 378·34 | 382·37 | 382·64 |
| 62·0 | 383·73 | 519 | 85 | 377·23 | 377·63 | 382·73 | 381·63 |
| 63·2 | 383·78 | 474 | 90 | 377·87 | 378·37 | 382·37 | 382·27 |
| 64·0 | 383·83 | 510 | 95 | 377·71 | 378·45 | 382·71 | 382·41 |
| 65·0 | 383·87 | 523 | 96 | 378·15 | 378·41 | 382·50 | 382·50 |
| 66·0 | 383·91 | 478 | 93 | 377·89 | 378·78 | 382·34 | 382·69 |
| 67·0 | 383·95 | 517 | 109 | 378·63 | 379·21 | 381·93 | 382·13 |
| 68·0 | 384·00 | 525 | 80 | 377·17 | 379·14 | 382·87 | 382·82 |
| 69·3 | 384·05 | 507 | 105 | 378·51 | 379·23 | 383·01 | 382·31 |
| 70·0 | 384·08 | 500 | 80 | 377·40 | 377·81 | 382·00 | 383·05 |
| 71·0 | 384·12 | 472 | 82 | 377·79 | 378·35 | 382·59 | 383·39 |
| 72·0 | 384·16 | 547 | 89 | 377·53 | 378·00 | 382·73 | 382·73 |
| 73·0 | 384·20 | 469 | 70 | 376·57 | 377·50 | 382·97 | 383·17 |
| 74·1 | 384·25 | 439 | 87 | 378·51 | 379·21 | 383·51 | 383·01 |
| 75·0 | 384·29 | 438 | 86 | 378·00 | 379·21 | 383·25 | 382·15 |
| 76·0 | 384·33 | 551 | 87 | 377·84 | 378·02 | 383·79 | 382·99 |
| 77·0 | 384·37 | 476 | 71 | 375·63 | 378·11 | 383·83 | 382·63 |
| 78·0 | 384·42 | 557 | 106 | 378·57 | 379·27 | 383·27 | 383·37 |
| 79·4 | 384·48 | 495 | 87 | 377·61 | 378·79 | 384·01 | 382·31 |
| 80·0 | 384·50 | 521 | 105 | 378·35 | 379·53 | 383·05 | 382·25 |
| 81·0 | 384·54 | 515 | 91 | 377·54 | 378·78 | 383·19 | 382·79 |
| 82·0 | 384·58 | 480 | 79 | 377·13 | 378·63 | 383·33 | 382·93 |
| 83·0 | 384·62 | 499 | 77 | 377·47 | 378·14 | 382·49 | 382·61 |
| 84·0 | 384·67 | 369 | 112 | 378·51 | 380·53 | 383·61 | 383·61 |
| 85·5 | 384·73 | 453 | 78 | 377·05 | 378·83 | 383·35 | 384·15 |
| 86·0 | 384·75 | 451 | 72 | 377·43 | 378·49 | 383·28 | 383·83 |
| 87·0 | 384·79 | 537 | 104 | 378·48 | 378·53 | 383·13 | 383·33 |
| 88·0 | 384·83 | 533 | 115 | 378·92 | 380·11 | 383·77 | 383·47 |
| 89·0 | 384·87 | 547 | 122 | 379·46 | 380·40 | 383·15 | 383·86 |

* Buffalo Cape Gauge.

TABLE 144.—THE ALBERT NILE (*continued*).

| Kilometres from Lake No. | L.S.W.L. | Area at L.S.W.L. | Width, Open Water. | Deepest Point in Bed. | Mean Bed-level. | Ground Level 10 metres from Edge of Papyrus. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Right. | Left. |
| 90·0 | 384·92 | 530 | 105 | 378·80 | 379·89 | 383·35 | 383·75 |
| 90·9 | 384·95 | 469 | 96 | 378·69 | 380·07 | 384·39 | 384·19 |
| 92·0 | 385·00 | 525 | 101 | 378·68 | 379·80 | 383·53 | 383·93 |
| 93·0 | 385·04 | 520 | 90 | 378·07 | 379·25 | 383·72 | 383·27 |
| 94·0 | 385·08 | 538 | 110 | 379·56 | 380·19 | 384·11 | 383·81 |
| 95·0 | 385·12 | 495 | 95 | 379·40 | 379·40 | 383·55 | 383·75 |
| 96·0 | 385·17 | 506 | 110 | 379·29 | 380·57 | 383·69 | 383·99 |
| 96·8 | 385·20 | 512 | 96 | 379·33 | 379·77 | 384·03 | 384·13 |
| 98·1 | 385·25 | 550 | 104 | 378·37 | 379·95 | 384·27 | 384·07 |
| 99·1 | 385·29 | 571 | 138 | 380·71 | 381·15 | 383·71 | 384·11 |
| 100·1 | 385·33 | 625 | 114 | 379·45 | 380·71 | 384·05 | 383·95 |
| 100·1 | 385·37 | 552 | 103 | 379·24 | 380·01 | 384·19 | 383·99 |
| 102·4 | 385·43 | 478 | 99 | 379·53 | 380·60 | 384·18 | 383·93 |
| 103·2 | 385·45 | 599 | 129 | 380·47 | 380·82 | 384·22 | 384·27 |
| 104·2 | 385·49 | 634 | 91 | 378·36 | 378·64 | 384·63 | 384·31 |
| 105·2 | 385·53 | 667 | 110 | 378·85 | 379·99 | 384·15 | 383·45 |
| 106·2 | 385·57 | 570 | 127 | 380·47 | 381·09 | 384·19 | 383·47 |
| 107·2 | 385·61 | 594 | 114 | 379·68 | 380·38 | 384·23 | 384·63 |
| 108·2 | 385·66 | 477 | 88 | 379·47 | 380·24 | 385·33 | 384·47 |
| 110·2 | 385·74 | 538 | 100 | 379·26 | 379·36 | 384·38 | 384·31 |
| 111·2 | 385·78 | 531 | 90 | 379·00 | 379·87 | 384·25 | 384·35 |
| 112·2 | 385·83 | 529 | 85 | 379·09 | 379·59 | 384·24 | 384·44 |
| 113·2 | 385·87 | 563 | 110 | 380·43 | 381·13 | 384·33 | 384·63 |
| 114·3 | 385·91 | 481 | 83 | 378·47 | 380·13 | 384·37 | 384·70 |
| 117·0 | 386·02 | 508 | 80 | 381·37 | 381·09 | 385·77 | 385·47 |
| 120·0 | 386·14 | 413 | 88 | 381·31 | 381·44 | 385·11 | 385·41 |
| 121·8 | 386·22 | 457 | 91 | 380·39 | 381·31 | 386·19 | 385·99 |
| 124·5 | 386·33 | 477 | 106 | 381·32 | 381·83 | 386·62 | |
| 127·0 | 386·44 | 435 | 107 | 381·73 | 382·38 | 385·73 | 386·73 |
| 130·4 | 386·58 | 433 | 113 | 381·66 | 382·74 | 386·86 | 386·66 |
| 133·7 | 386·72 | 475 | 97 | 380·81 | 381·85 | 386·51 | 387·01 |
| 136·1 | 386·82 | 485 | 110 | 380·66 | 382·42 | 386·46 | 386·96 |
| 139·0 | 386·94 | 497 | 106 | 380·90 | 381·26 | 386·70 | 386·50 |
| 141·3 | 387·04 | 510 | 96 | 380·71 | 381·87 | 387·41 | 387·21 |
| 144·1 | 387·16 | 457 | 95 | 382·24 | 382·47 | 386·22 | 387·24 |
| 146·8 | 387·27 | 415 | 87 | 381·77 | 382·72 | 386·97 | 387·87 |
| 149·3 | 387·37 | 475 | 97 | 382·29 | 382·76 | 387·89 | 387·19 |
| 152·4 | 387·51 | 436 | 88 | 381·73 | 382·65 | 387·43 | 387·83 |
| 155·0 | 387·61 | 485 | 117 | 382·65 | 383·47 | 388·05 | 387·05 |
| 157·6 | 387·72 | 452 | 88 | 382·17 | 382·64 | 387·47 | 387·17 |
| 159·5 | 387·80 | 443 | 84 | 381·96 | 382·59 | 388·16 | 388·76 |
| 161·5 | 387·88 | 486 | 112 | 382·35 | 383·49 | 387·35 | 387·35 |
| 164·4 | 388·01 | 492 | 98 | 382·39 | 382·99 | 388·49 | 388·49 |
| 166·0 | 388·08 | 457 | 106 | 382·57 | 383·77 | 388·37 | 388·87 |
| 168·4 | 388·18 | 412 | 93 | 382·52 | 383·75 | 388·78 | 387·88 |

TABLE 144.—*continued.*

| Kilometres from Lake No. | L.S.W.L. | Area at L.S.W.L. | Width, Open Water. | Deepest Point in Bed. | Mean Bed-level. | Ground Level 10 metres from Edge of Papyrus. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Right. | Left. |
| 172·6 | 388·35 | 449 | 104 | 383·53 | 384·04 | 388·88 | 388·38 |
| 175·9 | 388·48 | 410 | 131 | 384·53 | 385·34 | 387·73 | 389·33 |
| 178·3 | 388·58 | 381 | 74 | 382·65 | 383·43 | 389·25 | 389·15 |
| 181·3 | 388·72 | 385 | 92 | 383·69 | 384·54 | 388·79 | 384·49 |
| 183·8 | 388·82 | 378 | 116 | 385·11 | 385·57 | 389·41 | 388·91 |
| 187·0 | 388·95 | 440 | 87 | 382·46 | 383·91 | 389·56 | 389·46 |
| 190·1 | 389·08 | 432 | 91 | 381·40 | 384·34 | 388·20 | 389·80 |
| 192·2 | 389·18 | 472 | 95 | 383·39 | 384·22 | 389·09 | 389·59 |
| 195·4 | 389·31 | 482 | 88 | 382·65 | 383·84 | 390·15 | 390·15 |
| 198·1 | 389·42 | 459 | 101 | 383·47 | 384·89 | 390·07 | |
| 201·3 | 389·56 | 420 | 110 | 384·02 | 385·84 | 390·22 | 389·42 |
| 203·3 | 389·64 | 439 | 100 | 384·51 | 384·25 | 390·31 | 389·21 |
| 207·4 | 389·81 | 467 | 86 | 382·40 | 384·38 | 389·40 | 390·00 |
| 211·0 | 389·96 | 376 | 102 | 384·87 | 386·27 | 389·67 | 390·57 |
| 214·0 | 390·08 | 382 | 114 | 385·21 | 386·73 | 390·51 | 390·91 |
| 216·6* | 390·20 | 466 | 121 | 383·84 | 386·35 | 389·44 | 391·14 |

* About 10 kilometres downstream of Hillet el Nuêr.

37. **The White Nile.**—From its head at the mouth of the Sobat to Khartoum the White Nile has a length of 848 kilometres. The river runs due north in almost a straight line. It is really not a river but a kind of lake. The fall in summer is 10·4 metres, and in flood 6·8 metres owing to the Blue Nile flood throwing the White Nile into a backwater. The following table is interesting:—

TABLE 145.—THE WHITE NILE.

| Locality. | Distance in kilometres from the Head. | R.L. of Low Supply. | R.L. of Flood. | Difference in metres. | Flood Discharge. Cubic metres per second. | Low Supply Discharge. |
|---|---|---|---|---|---|---|
| Head | 0 | 385·1 | 388·4 | 3·3 | 1500 | 580 |
| Malakal | 33 | 384·8 | 388·0 | 3·2 | | |
| Kodok | 98 | 384·0 | 387·3 | 3·3 | | |
| Melut | 173 | 383·1 | 386·2 | 3·1 | | |
| Renk | 358 | 381·1 | 383·7 | 2·6 | | |
| Hillet Abbas | 518 | 378·3 | 381·4 | 3·1 | | |
| Dueim | 638 | 377·2 | 381·6 | 4·4 | | |
| Geteina | 753 | 376·0 | 381·4 | 5·0 | | |
| Khartoum | 848 | 374·6 | 381·6 | 7·0 | 0* to 1700 | 500 |

* When the Blue Nile is at its highest the discharge of the White Nile is zero.

At the head, the flood discharge is 1500 cubic metres per second, and

the low supply is 550. At its tail at Khartoum the flood discharge after the Blue Nile has fallen away is 1700, and the low supply discharge is 500.

Whether the lake of which the Albert Nile plain is the relic had a discharge over a sill in the neighbourhood of Tewfikia, or whether the White Nile after its formation eroded back till it captured the Sobat, and with it the drainage of this basin, need not detain us, although the brusque bend from the Sobat into the White Nile rather suggests the latter theory. The hydraulic engineer is concerned with things as he finds them, rather than with questions of palæogeography, which interest him solely from the light they may throw on the future evolution of the watercourse. The colour of the water of the Sobat River in flood gives its name to the White Nile. At Tewfikia, near the head of the White Nile, is a gauge which has been read since April 1903 ; but the chief gauge on this part of the river is that at Malakal, between Tewfikia and Kodok, where a regular station and hydrographic bureau for the White Nile system have been fitted up. Opposite Tewfikia is an island on the far side of which lies the Bahr el Harami, a continuation of the Lolle, so called because used by the slave-traders to avoid Baker's station at Tewfikia. For the first 358 kilometres the river has a waterway of from 300 to 500 metres in width with numerous islands. The mean width may be taken as 425 metres in low supply when the river is within banks. For the next 490 kilometres to the tail the mean width of water surface is 850 metres in low supply. The general depth of water in low stage is 4 metres, and 7 metres in flood. On either side of the waterway of the upper reach is a low ridge swamped in flood, and beyond that again is a deep depression, deep in the centre and rising to the ridge on one side and to the high land and forest on the other. Each depression may be 3 kilometres in width where it is wide and a few hundred metres where it is narrow, so that the flooded valley may have a width of 6 kilometres in places. The ridges are about 3 metres wide, and broken by openings through which the water passes in and out of the marshy depressions. The depressions are covered by a dense growth of reeds. When the reeds are burnt, one can traverse the marshes on foot. At Gebelein (between Renk and Hillet Abbas) the side depressions contract and the forests come nearer the river. At the Abu Zeid ford, 50 kilometres further to the north, is a serious obstacle to navigation when the river is low, in the shape of a very broad sheet of shingle studded thick with freshwater oysters. This bar is 6 kilometres long, as hard as stone, and has in very low summer a depth of water over it of only 50 centimetres. The swamping now visibly decreases, and the width of the river varies from 700 to 900 metres. Some 30 kilometres north of the railway bridge downstream of Abu Zeid the sudd grasses disappear, and though there is flooding there are no swamps. We have

now some well-cultivated islands in the river, for the negroes have come to an end and the Arabs inhabit the country. The summer channel in the 490 kilometres upstream of Khartoum is 850 metres wide and the flood channel 4·3 kilometres. The summer depth of water is about 4 metres.

We are here in a pulsating lake rather than a river, and especially so in flood, when the waters of the Blue Nile, as they rise, raise the level of the White Nile. When the Blue Nile begins to rise the level of the tail of the White Nile must rise with it, and more and more of the White Nile surface is levelled in this way till on the full flood the backwater curve extends at least as far south as Hillet Abbas, 300 kilometres from Khartoum. When the Blue Nile is rising rapidly it may, and does, sometimes happen that the discharge of the White Nile is insufficient to raise its own level, and in this case Blue Nile water will creep up the White Nile below the lighter current of the latter. The necessary condition for this state of affairs is simple. If the discharge of the White Nile is less than the product of the area of its level surface by the rate of rise of the Blue Nile, water from the latter will be required to make good the deficiency. In symbols, if Q is the White Nile discharge per unit of time (second or day) at any section, A the area of that portion of its surface which is level (or practically so) from Khartoum to that section, and $m$ is the rise of the Blue Nile in the same unit of time ; $Q-mA$ is the quantity of water that flows from the White Nile to the main river. If this is zero, the discharge of the White Nile is just sufficient to fill its trough at the same rate as the Blue Nile rises; if negative, the discharge is insufficient, and water will flow up from the Blue Nile. That this sometimes happens is evidenced by the existence of two islands or sandbanks on the White Nile just upstream of the junction, and the late Mr Thomas Barron informed us that on one occasion he had noted an upstream flow of the water hardly sufficient to move the vanes of a current-meter. Until sections of this basin are available, any attempt at evaluating the quantity $Q-mA$ must be to a large extent guess-work, and the expression itself gives only a first approximation to what really happens. The second approximation ought to take account of the backwater curve and of the time a flush takes to send its effect up the White Nile. The rate of travel will be approximately $\sqrt{(9{\cdot}8H)}-v$, where H is the hydraulic mean depth in metres and $v$ is the velocity of the White Nile current in metres per second. With a hydraulic mean depth of 5·5 metres (as at Dueim in flood), the rate of travel of the effect of a flush will be about 650 kilometres per day, allowing for a current of 0·5 metre per second in the White Nile.

On the other hand, once the Blue Nile begins to fall, the discharge of the White Nile at the junction will now become $Q+mA$, where $m$ is the rate of fall. The discharge of the Upper White Nile goes on increasing till

November, and though A decreases as the basin empties, it does so at first at a less rate than *m* increases for a time. The net result is that the discharge of the White Nile at Khartoum goes on increasing and reaches its maximum about the middle of October—a fortnight to three weeks before the maximum at its head, and a month after the maximum discharge of the Blue Nile. (See fig. 20.)

The slope on the White Nile is so low that its stored-up water cannot escape fast enough to keep pace with the fall of the Blue Nile. The consequence is that the latter is retarded in its fall, by a sort of reversal of the previous effect. On the fall, therefore, the tail of the Blue Nile is in

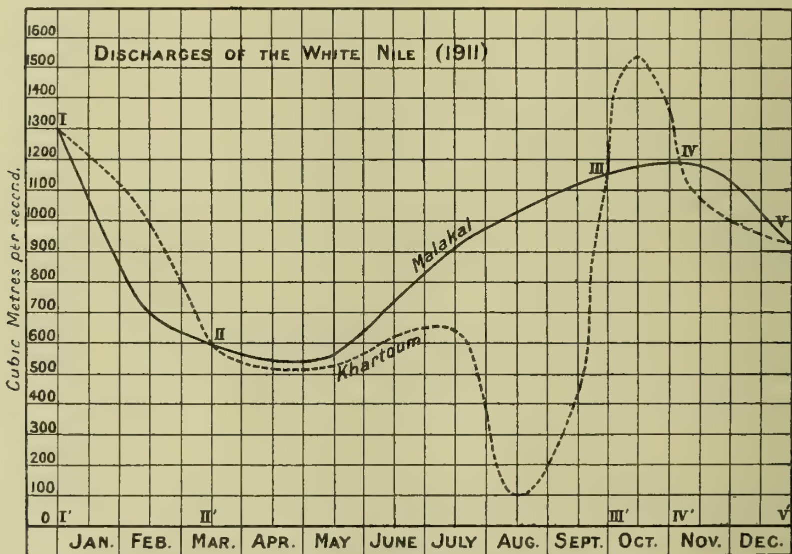



FIG. 20.

a backwater, and the gauge records higher readings than the discharge would warrant, and is henceforth worthless as a measurer of discharges.

We have devoted some space to the discussion of this effect, because it occurs at various other places on the Nile—wherever in fact a rapidly rising or torrential river is joined by a sluggish one with a wide, shallow basin. Thus we find exactly the same action at Lake Albert; at Lake No; at the junction of the Sobat with the Albert Nile; at the confluence of the Blue Nile and White Nile; and to a less extent, because the wide trough is absent, at the confluence of the Atbara and the Main Nile.

We make use of this stretch of the White Nile to illustrate some points in the use of discharge-time diagrams, and incidentally to calculate the evaporation from the surface of the river—an important factor in view of the possibility of constructing a reservoir at the tail.

*Some Points in the Use of Discharge-time Diagrams.*—These may be illustrated by the diagrams for Malakal and Khartoum on the White Nile.

The diagram for a given station may be considered as built up of the areas representing the volumes passing in successive units of time (here the second). Hence the area between two ordinates PM and QN gives the *total volume* which has passed the station for which the curve is drawn *between the times* represented by OM and ON (fig. 21).

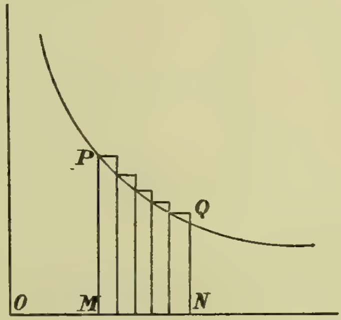


FIG. 21.

It will be seen that the curves cross about 1st January, 15th March, 1st October, 7th November, and again 31st December or 1st January, 1912. These points and the corresponding dates are represented by I, II, III, IV, V, and I′, II′, III′, IV′, V′ respectively (fig. 20).

The total volume that passed Malakal from 1st January to 15th March is represented by the area I, II, II′, I′, I, along the full line. The total area that passed Khartoum between the same dates is represented by the area I, II, II′, I′, I, along the dotted line. The difference, or the area between the dotted and full line from I to II, is the amount contributed by the trough between these dates.

Strictly we ought to add to ordinates at Khartoum small amounts to represent the loss, from evaporation, of water which would have passed Khartoum but for this wastage, and in the same way we should subtract from the ordinates for Khartoum an allowance (if necessary) for infiltration, tributary khors, and direct rainfall, between Malakal and Khartoum. As the White Nile at Khartoum in April is discharging less than at Malakal, we must put down the difference to loss from evaporation. (Defiltration may in this reach be excluded, as the soil is so impervious that wells sunk a few metres from the river are but little affected by its rise and fall.)

From II′ to III′ the trough is filling up, gradually at first, owing to the natural rise of the White Nile itself, but rapidly from the beginning of July, when the rise of the Blue Nile begins to hold up the White Nile in its lower reaches. The area between the full and dotted curves is the volume impounded in the 820 kilometres from Malakal to Khartoum. Immediately after the end of September the fall of the Blue Nile permits of the discharge of this impounded water, which goes on till 7th November, when another phase of the economy comes into action. The lower reaches are now nearly clear of the impounded water, but the upper reaches are still rising, owing to the late maximum of the Sobat, and water is now wanted to fill them. This explains the detention implied by the descent of the dotted curve below the other from 7th November to 31st December.

Had the point V been at the level of I, we should have had a complete cycle, for the initial and final states of the river at both stations would have been similar, and in this case we could have stated that areas (II, III+IV, V) should have equalled areas (I, II+III, IV) but for losses from evaporation and gains from tributaries and direct rainfall during the year. We can obtain a close measure of the latter by multiplying the mean rainfall over the river surface by the mean area of the surface in the year. The mean rainfall along the river was 540 millimetres in 1911 (see *Report on the Rains of the Nile Basin for* 1911). The mean area of the surface may be put at 700 square metres, and the total volume of direct rainfall on the river at 310 million cubic metres, or 10 cubic metres per second. Compared with the run-off from tributary khors, this must be small, and we may *estimate* the latter at five times the former. This procedure will give us 60 cubic metres per second as the amount by which the ordinates of Khartoum curve have to be diminished. Since, however, practically all the rainfall occurs from May to October, we must double this value and apply it to these six months only. When we do this we find the following:—

| | | | |
|---|---|---|---|
| Area II, III (reduced) | = 32 square cm.* | Area I, II . . | = 9 square cm.* |
| IV, V . . | = 4 ,, | III, IV . . | = 7 ,, |
| Sum (A) . | 36 ,, | Sum (B) . | 16 ,, |

Excess of (A) over (B) = 20 square cm.*

Now, on the scale of the original diagram, an area of 24 square centimetres represents $100 \times 365 \times 86{,}400$ cubic metres, or 1 square centimetre represents 130 million cubic metres. Hence the total evaporation in 1911 may be put at 2600 million cubic metres, and this from a mean surface of $820{,}000 \times 700$, or 574,000,000 square metres. This gives a mean annual evaporation of 4530 millimetres. But since the trough was emptier at the end of 1911 than at the beginning, we must apply to the above volume a diminution to represent the mean fall in the gauges (0·30 metre) multiplied by the mean area of the surface. Since, however, we have to divide again by this mean area, we may simply subtract the fall from the mean annual evaporation as above. We thus obtain a corrected value of 4230 millimetres, which represents a daily average of 11·6 millimetres. The daily average for the year given in Table 44 is 9·5 millimetres, and we may conclude that the values there given for the White Nile are too low by about 22 per cent.

The difference of the mean discharge in April between Malakal and Khartoum is 30 cubic metres per second, and the depletion of the trough accounts for 40 cubic metres per second, or 70 cubic metres per second in all. If this is considered as evaporated off an area of 530,000,000 square metres, we have a daily evaporation for the White Nile of 11½ millimetres

* On the original diagram, which was 2·5 times size of fig. 20.

TABLE 146.—MONTHLY MEANS OF MALAKAL GAUGE-READINGS (in metres).

| Years. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1903 | Commenced on Apr. 18, 1903. | | | (10·10)* | 10·46* | 11·32* | 11·77* | 12·27* | 12·93* | 13·23* | 13·35* | 13·38* | (12·090*) |
| 1904 | 12·93* | 11·23* | 10·82* | 10·74 | 10·97* | 11·63* | 12·18* | 12·62* | 12·94* | 13·11* | 13·16* | 12·94* | 12·106* |
| 1905 | 11·45* | 10·82* | 10·32* | 9·89* | 9·92* | 10·38* | 11·01* | 11·44* | 11·80* | 11·97* | 12·06* | 11·97* | 11·086* |
| 1906 | 11·21* | 10·46* | 10·45* | 10·23* | 10·22* | 10·92* | 11·44* | 11·81* | 12·17* | 12·36* | 12·41* | 12·30* | 11·332* |
| 1907 | 11·20* | 10·52* | 10·38* | 10·34* | 10·23* | 10·80* | 11·35* | 11·84* | 12·10* | 12·21* | 12·19* | 11·68* | 11·237* |
| 1908 | 10·81* | 10·37* | 9·96* | 9·80* | 10·04* | (10·58) | 11·28 | 11·79 | 12·11 | 12·36 | 12·49 | 12·49 | 11·173 |
| 1909 | 12·00 | 10·79* | 10·28 | 10·48 | 10·71 | 11·17 | 11·61 | 12·10 | 12·68 | 13·00 | 12·88 | 12·82 | 11·710 |
| 1910 | 12·63 | 11·39 | 10·45 | 9·98 | 10·17 | 10·83 | 11·34 | 11·74 | 12·09 | 12·33 | 12·43 | 12·43 | 11·485 |
| 1911 | 11·93 | 10·71 | 10·30 | 10·07 | 10·13 | 10·78 | 11·37 | 11·70 | 11·97 | 12·11 | 12·16 | 11·75 | 11·248 |
| Mean, 1903–12 | 11·77 | 10·79 | 10·37 | 10·18 | 10·32 | 10·94 | 11·48 | 11·92 | 12·31 | 12·52 | 12·57 | 12·42 | 11·47 |

* Tewfikia = Malakal.

TABLE 147.—MALAKAL MEAN DISCHARGE (in cubic metres per second).

| Years. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1903 | Commenced on Apr. 18, 1903 | | | 560* | 645* | 906* | 1049* | 1233* | 1637* | 1920* | 2045* | 2078* | 1341* |
| 1904 | 1637* | 875* | 736* | 715* | 784* | 1000* | 1197* | 1412* | 1646* | 1800* | 1850* | 1646* | 1275* |
| 1905 | 942* | 736* | 610* | 518* | 524* | 625* | 798* | 940* | 1060* | 1119* | 1511* | 1119* | 845* |
| 1906 | 868* | 645* | 642* | 587* | 585* | 767* | 940* | 1063* | 1193* | 1275* | 1300* | 1245* | 926* |
| 1907 | 865* | 660* | 625* | 615* | 587* | 730* | 915* | 1074* | 1165* | 1209* | 1201* | 1018* | 889* |
| 1908 | 733* | 622* | 532* | 500* | 548* | 675 | 893 | 1056 | 1169 | 1275 | 1340 | 1340 | 890 |
| 1909 | 1130 | 727 | 600 | 650 | 707 | 854 | 993 | 1165 | 1448 | 1700 | 1594 | 1546 | 1093 |
| 1910 | 1418 | 927 | 645 | 536 | 574 | 739 | 912 | 1039 | 1161 | 1260 | 1310 | 1310 | 986 |
| 1911 | 1105 | 707 | 605 | 554 | 566 | 725 | 921 | 1025 | 1119 | 1169 | 1189 | 1042 | 894 |
| Mean, 1903–11 | 1087 | 737 | 624 | 582 | 613 | 780 | 958 | 1112 | 1289 | 1414 | 1442 | 1372 | 1001 |

* Malakal inferred from Tewfikia.

per day. But if we take the sixty-nine days from the 7th February 1911 to the 16th April, and compare the water passing Malakal with that passing Khartoum twenty-two days later, during an interval of time that the Albert Nile, the Sobat, the White Nile, and the Blue Nile were all falling regularly without any freshets, we find that the difference in discharge was 44 cubic metres per second while the depletion of the trough supplied 60, making 104 cubic metres per second in all. This was evaporated off an area of 530,000,000 square metres, giving a daily evaporation of 17 millimetres per day. If now, reference is made to Table 44, it will be found that the evaporation for March on the White Nile is considered as 13 millimetres per day, while Mr Turstig's observations at Khartoum made it 13·3. We consider that it would be safe to take 15 millimetres per day as the evaporation off a reservoir on the White Nile; certainly for the upper half of the reservoir water. (See also Appendix I.)

38. **The Blue Nile.**—Compared with any river we have yet described, the Blue Nile is a true mountain stream. Draining the central and more rainy part of Abyssinia, it is the principal source of the Nile in flood. Whatever waters it receives it carries to the Nile, and it is the true parent of the land of Egypt, for the deposit from its muddy waters is that Nile mud which has made Egypt. The Atbara carries waters which are more muddy than those of the Blue Nile, but compared to the Blue Nile the Atbara is a small river, and its contribution is low by the side of that of the larger stream.

"Abyssinia, the country in which the Blue Nile has its source, stretches far south of the White Nile. It consists of table-lands from 2000 to 3000 metres high, with peaks rising to more than 4000 metres. In its structure, archaic rocks, gneiss, and schist take part, and these form the core. On them are beds of sandstone; above these, large sheets of basalt and trachyte have overflowed. Even if the origin of the table-land is connected with a crustal elevation, its present height depends essentially on the protective volcanic covering. In the east it descends abruptly to the plains along the coast of the Red Sea, in the west to the low lands of the White Nile. In the north and south it passes into the adjacent mountainous countries, gradually losing in height and width. As the plateau is from 500 to 1000 metres higher in the east than in the west, the general slope is towards the Nile system: the watershed therefore lies near to the steep eastern declivity." *

Where the surface is at all flat, it is covered with a layer of black mould whose fertility equals that of the Nile deposit of Egypt, and in places three crops are easily obtained in the year. But the outstanding feature of Abyssinia is the deep gorges cut by the river through the upper volcanic layer. Wherever the underlying sandstone has been reached

* Pietsch, *Abflussgebiet des Nils*, p. 30.

The White Nile, Tewfikieh.

The White Nile, Kodok.

Blue Nile and Lake Tsana.

Blue Nile 7 kilos from Lake Tsana.

Blue Nile below Lake Tsana.

erosion has proceeded rapidly to the primitive rock below, into which the cañon is continued. "The ravines of Abyssinia, which are often several kilometres broad and more than 1000 metres deep, show therefore a constantly recurring cross section. The upper half of the side of the valley is exceedingly steep, being formed of the hard basalt; then there follow terraced plateaux, one above the other, corresponding to the sandstone. In the lowest part the river has cut for itself in the primitive rock a deep, narrow bed with almost vertical walls." * These deep gorges have rendered approach to the river almost impossible in many parts, and in consequence much of the Blue Nile system has not yet been surveyed.

The principal tributary of the Blue Nile, the Abai, rises at a height of about 2700 metres above sea-level, and after a course of 110 kilometres falls into Lake Tsana. Lake Tsana lies at an altitude of about 1760 metres, and has an area of about 3000 square kilometres and a catchment basin of about 14,000 square kilometres irrespective of the lake area. On the 31st January 1903, after a very poor rainfall, Mr C. E. Dupuis found the discharge 42 cubic metres per second. Calculating from his cross section, it seems that the maximum discharge may be 200 cubic metres per second. As at Lake Victoria, possibly not more than one-twelfth of the rainfall finds its way into the lake; and, once there, the greater part is evaporated. Little seems to leave the lake, which would consequently make a comparatively poor reservoir. The land rises from the lake in gently undulating downs as a rule. Wherever observed by Mr Dupuis, the lake was shallow. There are many islands, and some of them considerable ones. The rivers feeding the lake are the following: the Abai, discharging 9 cubic metres per second in January 1903, the Reb 2 cubic metres, the Gumara 2, the Magetch 0·3, the Arno Garno 0·3, the Gelda 0·5, the Unfraz 1·2, and many smaller streams, say 1·7—or 17 cubic metres per second in all. This of course was in the dry season. Mr Dupuis considers the evaporation as 4 millimetres per day.

Between Lake Tsana and Roseires, on a length of about 975 kilometres, the Blue Nile falls some 1310 metres; between Roseires and Sennar, on a length of 288 kilometres, it falls about 35 metres; and between Sennar and Khartoum, on a length of 359 kilometres, it falls about 64 metres. The cross sections of the river at Wad Medani, 200 kilometres above Khartoum, and at Khartoum are given on Plate V.

From Roseires the river is running in a plain of its own formation, dating probably from days when, like the Gash and Hawash of to-day, the flood was insufficient to make its way to the main river and disappeared in its own alluvial cone. Russegger recognises five strata: recent alluvium, coarse-grained conglomerates of quartz pebbles in hard alluvium, older alluvium with kunkar, conglomerate, and fresh-water lime—which all

* Hietsch, *op. cit.*, p. 31.

bear witness to the varying regimen of the river. To anyone sailing up the river, the alluvial nature of the banks is manifest, and Dr Hume points to the evidence of former lacustrine conditions in the existence of kunkar. In general the strata slope with the river, but occasionally where the river has cut through an alluvial cone formed by a branch transverse to the present course, the layers slope upstream. Everywhere in this reach the river has cut deep into the alluvium, and in places has formed cliffs as much as 15 metres in height. Normal fluvial action may be studied at every bend. The concave bank is generally a steep, sometimes a high cliff, and is crowned by old forest, and the convex bank is low, largely covered in flood, and consequently covered with scrub rather than forest.

At Sheikh Talha the river flows through a narrow gorge cut in the conglomerate, and at Abdin expands considerably, and is much obstructed by sandbanks, which form a serious obstacle to navigation after the river has fallen to half its flood height.

In flood and early winter the river is navigable up to the Roseires Cataract. The width of channel may be considered as varying between 350 and 700 metres, with an average width of 500 metres. The river rises from 9 to 12 metres in flood, and has a velocity in high floods of 3 metres per second. Rivers with such velocities scour out their beds very severely and deposit silt in low floods, and for the discharges in the time of low supply cross sections should be annually established and discharge tables made depending on the sections. The summer discharge varies from 50 to 300 cubic metres per second, with a velocity of 75 centimetres per second, and the flood from 6500 to 13,000 cubic metres per second. The behaviour of the river is shown in Tables 114, 115, and 121. The beginning of May is generally low water, and the beginning of September high water. The winter discharge may be taken as 500 cubic metres per second.

The tributaries south of Roseires are the following: on the right bank, the Bolassa, the Durra, the Fatsam, the Bir, and the Temsha—veritable torrents; and on the left bank, numerous streams from north and north-west of Addis Ababa, the Anjur, the Didessa (the latter from 100 to 150 metres wide), and the Yabus or Dabus (a perennial stream). North of the last is the Tumat. The Didessa is about 350 kilometres long, the Yabus and the Tumat 200 each. It is not at all improbable that in the valley of the Didessa far better reservoir sites could be found than at Lake Tsana. There are important reaches here with very little slope and with valleys resembling rather those of Uganda than the typical cañons of Abyssinia.

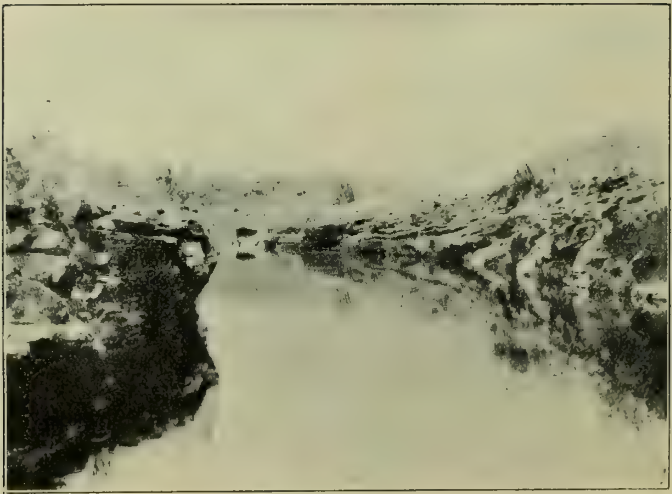
"The Didessa is the most important river that flows into the Abai except the combined Adabai and Wunchit, which join it in latitude 10° 2′, before the great river turns to the west. The discharge is one of enormous fluctuations. At the mouth there are two channels 100 and 110 metres across, and the flood rise is over 1·5 metres.

River Reb (Lake Tsana).

Blue Nile below Lake Tsana.

River Atbara near Galabat.

River Atbara at Wad Abu Siman.



Atbara River. Sandstone Gorge.

"From the Didessa northwards the serious business of gold-washing begins. About £60,000 worth is got from the Dabus, and £20,000 from other sources." *

North of Roseires there are two important tributaries on the right bank, the Dinder, north of Sennar, and the Rahad, just north of Wad Medani. Both these streams run only in flood and are dry in winter and summer. The Dinder has a bed width of about 120 metres, depth 4 metres in good flood, and a velocity of 2 metres per second, which gives a discharge of about 1000 cubic metres per second in a high flood. The Rahad has a bed width of 60 metres, depth of 3 metres in a good flood, and a velocity of 2 metres per second, which gives a discharge of 400 cubic metres per second in a good flood. In 1911, a poor year, the two rivers discharged 700 and 200 cubic metres per second respectively. The deltas of the Blue Nile, the Dinder, and the Rahad are formed of the richest Nile mud.

The rapid alternations of level at Roseires in flood demonstrate that the lower basin of the Abyssinian Blue Nile—that is, the basin of the Khor Tumat, Bolassa, Yabus, Durra, and Didessa—is of capital importance for the flood, which will depend on the rainfall here rather than in the sheltered basin of Lake Tsana. It is much to be desired that rainfall observations should be extended into this important region. Those that are now taken in Abyssinia, though of considerable importance, appear to have little direct connection with the flushes at Roseires.

39. **The Atbara.**—The Atbara, the last tributary of the Nile, flows into the main river at Atbara, 40 kilometres south of Berber. It is essentially a torrent fed by the rains of northern and north-eastern Abyssinia, and since these rains begin late and end early (see Table 8), the Atbara rises quickly from June to high flood in August and falls again quickly through September. There is but little capacity for water on the steep slopes of its basin, and from October the springs do not supply enough to keep up a continuous flow in the channel. From then on the bed contains only numerous pools of water, which are always deep and often very extensive. It is not improbable that a considerable discharge of ground water still goes on, and this serves to maintain the pools, and possibly even to add a small discharge to the Nile.

Mr Dupuis has given a rough longitudinal section of the Atbara River. Rising within 16 kilometres of Lake Tsana, at a height of about 2000 metres above sea-level, in its first 300 kilometres it falls 1500 metres to 530 metres above sea-level, where it is met by the Salaam river. In the next 80 kilometres it falls 40 metres, and is then joined by the Settit or Takazze River, a larger and more permanent stream than the Atbara itself. Sixty kilometres lower down is the Khashm el Girba gauge, just upstream of El Fasher, and about 440 kilometres from the Nile. The Atbara is here

* Weld Blundell, *Geog. Jour.*, 1906, xxvii. p. 539.

about 470 metres above sea-level. One hundred and forty kilometres from Khashm el Girba is Gosrejeb, and about 150 kilometres further down Adarma. Finally, after a total length of about 880 kilometres, the Atbara flows into the Nile. At Gosrejeb its altitude is 410, at Adarma 380, and at Atbara about 365 metres above sea-level. In the last 280 kilometres there is therefore a fall of 45 metres, or about $\frac{1}{6000}$.* In this reach the river has a width of about 330 metres and depth in flood of 6 metres.

The Settit rises to the east of Lake Tsana, at an altitude of about 3000 metres, has a much more extensive basin than the Atbara, and, but for the fact that it lies mainly on the lee side of the plateau, would be a more imposing river than it is. Like other Abyssinian rivers, it runs in a deep gorge of its own erosion. Its slope varies between $\frac{1}{80}$ and $\frac{1}{600}$.

The principal tributaries of the Atbara are the Salaam and Settit, already mentioned. On its right bank between Gosrejeb and Adarma it is joined by the Gash River, which flows past Kassala and loses itself in the deserts. In years of extraordinary rainfall the Gash reaches the Atbara. The Gash at Kassala has a width of 150 metres, depth of 1 metre in flood, and discharge of 300 cubic metres per second.

It appears probable that there is a certain amount of compensation between the rainfall of the Atbara and that of the Blue Nile; owing to the fact that when the rain-bearing current is too far north it gives an increased flood on the Atbara and a decreased one on the Blue Nile, but the subject requires further study. All that we can state at present is that there have been some of the few years available for discussion when the rains reached far to the north, causing heavy floods on the Atbara and wash-outs on the Sudan railway, and that these were accompanied by a lessened Blue Nile flood.†

Tables 81 and 114 give the behaviour of this river. In 1902, a very low year, and 1904, a low year generally, the maximum discharge was about 2000 cubic metres per second, and in 1903 about 3000 cubic metres. In 1911 and 1912, two very low years, the discharges were 1700 and 2000 cubic metres per second. In high floods the Atbara can discharge about 4500 cubic metres per second. Its effect on the main river is very great, since its flushes come at a time when the trough is already nearly full. As a rough rule, it may be said that a given rise at Khashm el Girba, near the top of the flood, produces a rise of half the amount six or seven days later at Wadi Halfa—as may be seen from the gauge diagrams for 1909 and 1910 at Khashm el Girba and Wadi Halfa.

The Atbara contributes an amount of silt to the Nile proportionately greater than the Blue Nile. For this there are two reasons—the more torrential character of the river and the greater exposure of its basin to

* $\frac{1}{7600}$ in low stage, and $\frac{1}{5400}$ in flood.

† This certainly occurred, for example, in 1912.

Junction of the Atbara and Setît.

Junction of Atbara with Nile.

River Rahad at Sherif Yakub.

erosion. Sir Samuel Baker's description of the Atbara in flood undermining and tearing down its steep banks, and then churning up the mud, is delightful reading.

40. **The Nile from Khartoum to Aswan.**—Making use of the information which is obtainable, we may say that the Blue Nile is generally at its lowest between the 15th April and 15th May, with a mean low-water discharge of about 200 cubic metres per second, falling to nearly zero in certain years; it is at its highest between the 15th August and 15th September, with a mean maximum discharge of some 10,000 cubic metres per second, rising to 13,000 and falling to 6500 in maximum and minimum years. If the larger figure is correct, the Blue Nile bank at Khartoum is over a metre too low, and the town is liable to be flooded out.

We have not had a really high flood at Khartoum since the re-occupation of the Sudan. Those of 1906, 1908, and 1909 were threatening, but there was no inundation; but a flood like that of 1874 or 1878 would probably have swamped out the town.

If reference is made to paragraph 37, it will be seen that the effect of the flood of the Blue Nile in July, August, and September travels up the White Nile, holds back its waters, and converts the valley of the White Nile into a flood reservoir. When the Blue Nile falls rapidly in October and November, the discharge of the Nile is maintained by the stored-up waters in the White Nile and by the White Nile flood which has slowly travelled down its almost level bed. Tables 114 and 115 show this more clearly than any description could.

This reach of the river was surveyed and examined by the Survey Department in 1906, to investigate the possibility of constructing another dam as an alternative to heightening the Aswan dam. No suitable site was found which gave both sound rock for a foundation and large reservoir capacity.

The following description of the river from Khartoum to Aswan is from the pen of Mr T. D. Scott of the Survey Department, who was on the Survey and has kindly sent us the information:—

"At Khartoum the Blue Nile joins the White Nile, and the combined waters flow for 1885 kilometres to Aswan through a region of Nubian sandstone overlying an old eroded land surface of crystalline rocks of many kinds which has been laid bare at places in the course of the still incomplete degradation of the river's bed.

These crystalline rocks of the old underlying land surface offer a much greater resistance to the river's action than does the softer Nubian sandstone. Upstream, therefore, of the places where the former rocks are exposed degradation ceases for a time while the river cuts its way through the rocky obstacle. The river's course thus consists of a series of placid reaches of little slope separated by rocky rapids, called the Cataracts, where the slope is greater and the water more turbulent.

For the first 80 kilometres north of Khartoum the river flows N., thence to Berber (kilo 387 from Khartoum) the course is successively E., N.E. and N.

North of Berber the river turns N.N.W. to Abu Hamed (kilo 578), where it abruptly turns S.W. to Korti (kilo 872). From Korti the course swings round a bend back to north at Kerma (kilo 1145), whence it proceeds N. and N.E. past Wadi Halfa (kilo 1435) to El Derr (kilo 1671). From El Derr the river, after a short right-handed loop to the south, flows in a northerly direction to Aswan. To discover the factors which determine this course, further geological examination is required: it is clear, however, that in the Cataracts the varied nature of the crystalline rocks produces the many islands and winding channels.

As degradation is still in progress throughout the length described, the river is depositing no flood plains: cultivation therefore is confined to the few reaches where the natural conditions permit of artificial irrigation.

From Khartoum the river flows north in a wide channel of little slope ($\frac{1}{10,500}$ at low stage) through an open plain for about 75 kilometres to Gebel Royan. On the right-hand bank there are several pumping stations, and large areas are cultivated. There are also many fertile islands in this reach, but the left-hand bank presents a desolate appearance, the gravelly surface being quite unproductive.

After this stretch of 75 kilometres the river turns to the right round Gebel Royan and enters the Shabluka Gorge (kilo 77), where it has cut a narrow way through a mass of crystalline rocks rising high above the surrounding plain, apparently at a time before the surrounding country had been eroded to its present level. In this gorge, which is called the Sixth Cataract, the river has cut its way down to the level of the slope from Khartoum to the head of the next Cataract, and the typical Cataract conditions do not now prevail. The channel narrows to 190 metres at low stage, but there is only one slight trace of rapids—at the north end of the gorge by the island of Maskit (kilo 93).

From Shabluka the bed once again widens out, and the river flows at the same gentle slope to Garni Island (kilo 412) north of Abidia, receiving in its course its last tributary, the intermittent Atbara, at a point on the right bank 327 kilometres from Khartoum. There is a certain amount of cultivation at places on both banks in this long reach of river, and on the left bank opposite Zeidab a considerable quantity of cotton is grown on well-irrigated land.

At Garni Island there commences a series of Cataracts, including the Solimania, Baggara, and Mograt, which terminates below Abu Hamed at the downstream end of Mograt Island (kilo 605) and is called the Fifth Cataract. The mean slope of this Cataract is $\frac{1}{4400}$.

A stretch, of slope $\frac{1}{7800}$ and almost entirely free from islands, follows to Shirri Island (kilo 683), where the Fourth Cataract commences. At the head of this Cataract, at Es Salamat, on the left-hand bank, there occurs the only stretch of cultivation noticeable on the reach from Abu Hamed to the foot of the Fourth Cataract. The Fourth Cataract continues from Shirri Island at a mean slope of $\frac{1}{3200}$ to a point about 20 kilometres upstream of Merowe (kilo 822). This Cataract includes many rapids, the chief being Shirri and Kirbekan, and many islands—some of considerable size, such as Shirri, Us, Boni, Amri. From the head of the Fifth Cataract to the foot of the Fourth the aspect of the country becomes more and more barren and wild, but the succeeding stretch through Dongola Province to Abu Fatma (kilo 1148) is of a totally different character.

The river here flows at a gentle slope ($\frac{1}{13,000}$). At many places, level and cultiv-

able ground stretches on one or both banks for some distance from the river; there is comparatively little rock, but some long stretches of drift sand, especially on the right-hand bank where the river is flowing north. This province of Dongola is the most fertile stretch traversed by the river in its course from Khartoum to Aswan. Cultivation extends already over large areas, and is steadily spreading. At the downstream end of the province occurs the large cultivated island of Argo, and some fourteen kilometres downstream at Abu Fatma (kilo 1148) crystalline rock once more appears. From Abu Fatma to Halfa (kilo 1535) the river pursues its way through wild and desolate country, the mean slope is steep, and not less than thirteen separate reaches of rapids occur.

In rapid succession downstream of Abu Fatma occur the rapids of Hannek, Simit, and Shaban. In all three the rock is gneiss with granite bands, and the chief difference between them is in slope. At Hannek the water-level falls $4\frac{1}{2}$ metres in 5 kilometres, Simit has a slope of 3 metres in 6 kilometres, and Shaban of 4 metres in 16 kilometres. After 36 kilometres of little slope, Kaibar Rapids (kilo 1211) are reached. These are due to a low belt of gneiss rising through the sandstone, and have a sharp slope of about 3 metres in less than half a kilometre at low stage. At flood the belt of rock is practically submerged, and there is little slope. After about 90 kilometres of low slope the slope steepens, though without appearance of crystalline rock, past Sai Island to the Amara Rapids (kilo 1342), which are due to schistose rocks and which contain many islands. At Koyamatto (kilo 1275), and again just before Amara, the river bends right-handed through 90°.

A period of uninterrupted flow follows to Dal (kilo 1376), where coarse granite gives rise to steep rapids with a slope of 9 metres in 8 kilometres with several islands, small and large. About 10 kilometres further on at Akasha (kilo 1393) gneiss, striking north and south across the river, gives rise to rapids and turns the river back to a northerly course. Thereafter at short intervals follow the rapids of Tangur (kilo 1415), Ambugol (kilo 1438) and Atiri (kilo 1456), the two former sloping about $\frac{1}{1000}$, the latter about $\frac{1}{2000}$. These three groups of rapids are due to the exposure of granite and schists.

The Semna Rapids (kilo 1467) are most interesting. Here a band of red and grey gneiss crosses the river. At low stage the whole river flows through a narrow gap some 40 metres wide, in flood the barrier is submerged for most of its length, one small island only being visible. From inscriptions of the Twelfth Dynasty on the west bank it appears that the heights of floods of that period (about 1800 B.C.) were about $7\frac{1}{2}$ metres above those of the present day.

From Semna the river flows quietly past Sarras to Gemai (kilo 1510), where a mass of granite with diorite strikes across the river. For some 5 kilometres this structure gives rise to rapids, and then the granite practically disappears and is replaced by dark hornblendic rocks with dolerite veins through another 11 kilometres of rapids. In these latter, which are called the Abki Rapids, there are in flood some 200 islands. In low stage the slope of Gemai and Abki is $\frac{1}{1000}$.

The two last-mentioned rapids are usually taken as comprising the Second Cataract. The limits of the Third Cataract have been defined in various ways, but it seems simplest to group together all the rapids from Hannek to Semna inclusive under that title. Nine kilometres from the foot of the Second Cataract the river passes Halfa and thence flows for 345 kilometres at low slope (about $\frac{1}{13.000}$) through Nubian sandstone to the head of the First Cataract at Shellal. For the

first 235 kilometres the country is open, but from about Dakka the sandstone hills close in to form a narrow, steep-sided valley.

At Abu Hor and Kalabsha (kilo 1823) granite occurs, and at the latter place the channel contracts to the Bab Kalabsha, where probably there once existed steep rapids.

The First Cataract is different in character from the Second and Third Cataracts, for the channels are determined by fault lines and not by veins of softer rock. The water-level in the First Cataract falls about 6 metres in 5 kilometres to the town of Aswan (kilo 1885), whence the river pursues a course to the sea uninterrupted by any natural barriers.

At the head of the First Cataract stands the Aswan dam, which, holding up a head of 28 metres of water at the beginning of the low stage of the river, stores in the valley and bed upstream to near Wadi Halfa about 2½ milliards of cubic metres of water. Originally the head of water was only 21 metres, giving a content of one milliard. Before the dam was raised to its present height a thorough examination was made of the river from Wadi Halfa to Khartoum, to see whether there existed another suitable dam site. Three sites were selected as possible: at Dal (kilo 1381), at Koyamatto (kilo 1275), and at the head of Darmai Island (kilo 708)—a small island downstream of Us Island in the Fourth Cataract, where granite replaces the prevailing gneiss. These were geologically examined, and the upstream reaches were fully contoured. The net result was that none of these three sites satisfied the necessary conditions, and it was proved that the head of the First Cataract was the only suitable dam site on the whole stretch of river from Khartoum to the sea."

Between Wadi Halfa and Aswan the mean width of the river is 550 metres, and the mean depths in flood and summer are 9 and 2 metres. The velocity in summer falls to 50 centimetres per second, and rises to 2 metres per second in flood. The river in this reach is generally within sandstone, and great part is provided with gigantic spurs on both banks. These spurs perform the double work of collecting soil on the sides in flood and training the river in summer. They were probably put up by the great Rameses three thousand years ago, as some of the most massive of them have evidently been constructed to turn the river on a curve out of its natural channel on to the opposite side, in order to secure deep water in front of his temple of Jerf Husain ("Jerf" means steep, scoured bank). The spurs have been constructed with care, and as the courses of roughly dressed stone can be examined at fairly low water (we have never seen them at absolutely low water), it is evident that there has been no great degradation of the bed during the last two or three thousand years. The spurs near Toski have been turned, and might with great advantage to navigation be repaired.

At the foot of the First Cataract, opposite the town of Aswan, on the Island of Elephantine, has stood a Nile gauge from very ancient times. An officer belonging to the Roman garrison in the time of the Emperor Severus marked an extraordinarily high flood on the gauge. The

maximum flood-mark at the time of the visit of Napoleon's French savants was, however, 2·11 metres higher than the above. As the middle of Severus' reign was A.D. 200, and the visit of the French savants A.D. 1800, they concluded that the bed and banks of the Nile had risen 2·11 metres in 1600 years, or 0·132 metres per 100 years. The new gauge, divided into cubits and twenty-fourths, was erected in 1869, and has been recorded daily since then (a cubit = 54 centimetres). The zero of the gauge is R.L. 84·16.

In his report on the Hannek and Kaibar Rapids De Gottberg stated that the cataracts of the Upper Nile stored considerable quantities of water which maintained the low supplies of the Nile. In our opinion, however, the moment the daily fall of the river becomes less than the daily evaporation, all the stretches of ponded water cease to aid the stream, and if they are very extensive they diminish the discharge by their large evaporating area. The six cataracts of the Nile, with their numerous raised sills, moderate the floods and lengthen them out, and help to maintain the winter discharges in some measure ; but when the time of real low discharge has come in the burning months of April, May, and June, the great reservoirs of the Nile are the real sources of supply, and the only other sources are the infiltration water which percolates back into the Nile when its level is low.

There have been proposals to blast some of the cataract rocks to make channels navigable all the year round. It might be possible to blast central channels up which steamers could make way in summer, and the subject of cost might be studied ; but the railways serve the country so well that there seems to be no necessity for such works.

The water-power of the cataracts, for irrigation purposes and for the towns of Khartoum and Omdurman, will be no mean asset of the country one day.

The following tables give very approximate figures for the water-surface, sectional areas and volumes of the trough contents, which may be used until more exact study supplies the necessary data.

TABLE 148.—MEAN BREADTH OF THE NILE.

| Locality. | Length. Kilos. | Breadth. Metres. |
|---|---|---|
| Khartoum to Shabluka . . | 80 | 900 |
| Shabluka to Berber . . . | 290 | 900 |
| Berber to Abu Hamed . . | 210 | 900 |
| Abu Hamed to Shirri . . | 120 | 700 |
| Shirri to Abu Fatma . . . | 450 | 950 |
| Abu Fatma to Sarras . . | 340 | 710 |
| Sarras to Halfa . . . . | 50 | 430 |
| Total . . | 1540 | 800 |

TABLE 149.—SECTIONAL AREA OF THE MAIN NILE (APPROXIMATE) (in square metres).

| Locality. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Distances. km. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Atbara to Fifth Cataract | 2600 | 1900 | 1500 | 1250 | 1160 | 1800 | 2800 | 4500 | 6750 | 6100 | 4600 | 3300 | 69 |
| Fifth Cataract | 1800 | 1400 | 1100 | 900 | 800 | 1000 | 2000 | 4000 | 4850 | 4500 | 3500 | 2500 | 160 |
| Fifth Cataract to Fourth Cataract | 2500 | 1800 | 1300 | 1100 | 1000 | 1300 | 2500 | 5700 | 6950 | 6400 | 5000 | 3600 | 97 |
| Fourth Cataract | 1800 | 1400 | 1100 | 900 | 800 | 1000 | 2000 | 4000 | 4850 | 4500 | 3500 | 2505 | 110 |
| Fourth Cataract to Third Cataract | 2300 | 1700 | 1300 | 1100 | 1000 | 1300 | 2400 | 5400 | 6550 | 6100 | 4700 | 3300 | 313 |
| Third Cataract | 2600 | 2000 | 1500 | 1100 | 860 | 900 | 1900 | 4100 | 5450 | 5000 | 3900 | 3300 | 80 |
| Third Cataract to Second Cataract | 2600 | 2000 | 1500 | 1100 | 860 | 900 | 1900 | 4100 | 5450 | 5000 | 3900 | 3300 | 110 |
| Second Cataract | 1800 | 1400 | 1100 | 900 | 800 | 1000 | 2000 | 4000 | 4850 | 4500 | 3500 | 2500 | 200 |

CONTENTS OF THE TROUGH (in million cubic metres).

| Locality. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Khartoum to Shabluka | 140 | 110 | 100 | 90 | 90 | 110 | 140 | 210 | 290 | 260 | 210 | 160 |
| Shabluka to Atbara | 700 | 510 | 400 | 340 | 310 | 490 | 760 | 1220 | 1820 | 1650 | 1240 | 890 |
| Atbara to Fifth Cataract | 190 | 130 | 100 | 90 | 80 | 120 | 190 | 310 | 470 | 420 | 320 | 230 |
| Fifth Cataract | 290 | 220 | 180 | 140 | 130 | 160 | 320 | 640 | 770 | 720 | 560 | 400 |
| Fifth Cataract to Fourth Cataract | 240 | 170 | 130 | 110 | 100 | 130 | 240 | 550 | 670 | 620 | 480 | 350 |
| Fourth Cataract | 200 | 150 | 120 | 100 | 90 | 110 | 220 | 440 | 530 | 490 | 380 | 270 |
| Fourth Cataract to Third Cataract | 720 | 530 | 410 | 340 | 310 | 410 | 750 | 1690 | 2050 | 1910 | 1470 | 1030 |
| Third Cataract | 210 | 160 | 120 | 90 | 70 | 70 | 150 | 330 | 440 | 400 | 310 | 260 |
| Third Cataract to Second Cataract | 290 | 220 | 160 | 120 | 90 | 100 | 210 | 450 | 600 | 550 | 430 | 360 |
| Second Cataract | 360 | 280 | 220 | 180 | 160 | 200 | 400 | 800 | 970 | 900 | 700 | 500 |
| Total | 3340 | 2480 | 1940 | 1600 | 1430 | 1900 | 3380 | 6640 | 8610 | 7920 | 6100 | 4450 |

The table giving the mean contents is useful as enabling us to estimate the regulating and storing effect of the trough itself on the discharges. We observe that from October to April while the river is falling, the trough contributes to the discharge at the average rate of 370 cubic metres per second, or a total volume of 8·6 milliards of cubic metres in seven months. Not all of this, however, is available, as some 110 cubic metres per second are used in providing for evaporation. The net result is an average contribution of 260 cubic metres per second during the falling stage on the Khartoum to Wadi Halfa reach. A corresponding amount, viz. 8·6 milliards, is of course withheld from the flood during the rising stage. The effect of the trough is greatest not at highest and lowest stages, but when the river is rising or falling most rapidly, and exhibits itself not only in a modification of the discharge at these times, but also in a retardation of the dates of maximum and minimum.

This computation takes no account of the effect of seepage, which has already been studied in great detail in paragraph 12 for Egypt, where more data are available. But it may be stated generally that the effect of seepage is similar to that of the trough: water is taken from the river when it is rising and returned when it is falling. The slope of the ground water will be greatest when the river is rising or falling rapidly; but the establishment of the greatest slope will require time, and so there will be an interval between the date of greatest filtration effect and that of most rapid change of the river. Filtration has also the effect of retarding the maximum and minimum discharges.

A point that must not be lost sight of is that any scheme which increases the amount of water in the river at low stage deprives us of some of the water drawn from the falling trough, and from the return seepage.

TABLE 150.—REGULATING EFFECT OF THE TROUGH—KHARTOUM TO WADI HALFA.

| Month. | Mean Breadth. Metres. | Evaporation. Cubic metres per second. | Mean Trough Effect, in cubic metres per second. | Net Trough Effect, in cubic metres per second |
|---|---|---|---|---|
| January | 370 | − 50 | + 130 | + 80 |
| February | 350 | − 60 | + 120 | + 60 |
| March | 350 | − 70 | + 80 | + 10 |
| April | 340 | − 70 | + 60 | − 10 |
| May | 340 | − 80 | ... | − 80 |
| June | 340 | − 80 | − 120 | − 200 |
| July | 370 | − 80 | − 470 | − 550 |
| August | 470 | − 100 | − 870 | − 970 |
| September | 800 | − 170 | − 340 | − 510 |
| October | 630 | − 110 | + 830 | + 720 |
| November | 420 | − 80 | + 420 | + 340 |
| December | 390 | − 60 | + 160 | + 100 |

The two following tables give details of the basins and basin canals of Dongola Province. They are all new.

TABLE 151.—LIST OF BASINS IN DONGOLA PROVINCE.

| Name of Basin. | Projected, Under Construction, or Completed. | Total Area. | Total Cost. | Area to Date. | Cost to Date. | Remarks. |
|---|---|---|---|---|---|---|
| | | acres | £ | acres | £ | |
| Nuri | Completed | 1,600 | 490 | | | |
| Barkal | ,, | 350 | 300 | | | |
| Gureir | ,, | 600 | 475 | | | |
| Korti | ,, | 600 | 450 | ... | ... | No sluice: dug by natives. |
| Taka-Mora | ,, | 170 | Nil | | | |
| Affat | ,, | 900 | 610 | ... | ... | No tail escape. |
| Debbet el Fogara | ,, | 680 | 580 | | | |
| Gabria | Under construction | 900 | 250 | 400 | 70 | |
| Letti basins | ,, | 12,000 | 8,500 | 6,000 | 5,080 | |
| Megauda | Projected | 970 | 700 | Nil | Nil | |
| Kerma basins | Under construction | 80,000 | 50,000 | 60,000 | 30,093 | |
| Ordi | Projected | 1,300 | 400 | Nil | Nil | |
| Mogasir | Completed | 200 | 40 | ... | ... | No head sluice. |
| Argo basins | Projected | 7,000 | 5,000 | Nil | Nil | |
| | | 107,270 | 67,795 | | | |

*Résumé.*

| | Acres. |
|---|---|
| 8 basins completed, with a joint area of | 5,100 |
| 3 ,, under construction, with a joint area of | 92,900 |
| 3 ,, projected, with a joint area of | 9,270 |
| Total | 107,270 |

[TABLE

TABLE 152.—DIMENSIONS, LEVELS, AND DISCHARGES OF BASIN CANALS IN DONGOLA PROVINCE.

| Name of Basin. | Name of Canal. | Canal-bed Width. | Canal-bed Level. | Maximum Average. | | Average. | | Minimum Average. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | H.F.L. | Discharge. | H.F.L. | Discharge. | H.F.L. | Discharge. |
| | | | | R.L. | | R.L. | | R.L. | |
| Nuri . . | Nuri . | 2 | 250·50 | 253·0 | 8·0 | 252·4 | 5·0 | 251·6 | 3·0 |
| Barkal . | Barkal . | 1 | 250·50 | 252·7 | 1·0 | 252·00 | ·5 | 251·2 | ·3 |
| Gureir . | Gureir . | 1 | 247·50 | 249·7 | 4·0 | 249·0 | 2·0 | 248·2 | 1·0 |
| Korti . . | Korti . | 2 | 246·00 | 248·7 | 4·0 | 248·0 | 1·5 | 247·2 | Nil |
| Taka-Mora . | Taka-Mora | 0·75 | 245·00 | 247·4 | 1·0 | 246·7 | ·5 | 245·9 | ·2 |
| Affat . . | Affat . | 2 | 241·35 | 244·6 | 6·0 | 244·0 | 4·0 | 243·2 | 1·5 |
| Debbet el Fogara . | Debbet el Fogara . | 2 | 240·00 | 242·6 | 5·0 | 242·0 | 3·0 | 241·2 | 1·5 |
| Gabria . | Gabria . | 1 | 238·00 | 241·3 | 5·0 | 240·6 | 2·6 | 239·8 | 1·5 |
| Letti . . | Letti . | 8 | 236·00 | 240·00 | 25·0 | 239·3 | 18·0 | 238·5 | 10·0 |
| Megauda . | Megauda . | 2 | 236·25 | 229·4 | 5·0 | 238·7 | 3·2 | 227·9 | 2·0 |
| Kerma . | Selim . | 20 | 226·00 | 230·0 | 100·0 | 229·3 | 60·0 | 228·5 | 40·0 |
| Ordi . . | Ordi . | 2 | 227·00 | 229·85 | 8·0 | 229·15 | 5·0 | 228·4 | 3·0 |
| Mogasir . | Mogasir . | 1 | 227·00 | 229·4 | 1·0 | 228·7 | ·5 | 227·9 | 0·2 |
| Argo . . | Argo . | 7 | 225·50 | 228 2 | 14·0 | 227·5 | 8·0 | 226·7 | 5 0 |

*Note.*—All dimensions in metres, and discharges in cubic metres per second.

41. **The Nile from Aswan to the Cairo Barrage.**—From Aswan to the Barrage the length of the river is 968 kilometres in summer and 923 in flood. The slope in summer is $\frac{1}{13,000}$, and in flood $\frac{1}{11,800}$. The mean fall of the valley is $\frac{1}{10,800}$. The slopes of the river vary in the different mean reaches, the least being $\frac{1}{14,800}$ in the Kena Mudiria, and the greatest $\frac{1}{11,400}$ in Beni Suef. In a high flood with a rise of 9 metres at Aswan, the rise in Kena will be 9·5 metres and only 8·2 in Beni Suef. Table 129 gives the mean areas of cross sections of the Nile, while Table 131 gives the mean widths. Neglecting spill channels, we may state that in a high flood the mean area of the section of the Nile is 7500 square metres, and the mean width 900 metres. In the Kena Mudiria the area is 7000 square metres, and the width 800 metres, while in Beni Suef the mean area is 8000 square metres, and the mean width 1000 metres. Speaking generally, it may be stated that where the Nile Valley is narrow the slope of the river is small, its depth great, and width contracted; while where the valley is broad the slope is great, the depth small, and the width enlarged. The mean velocity in flood ranges between 2·0 metres and 1·0 metre per second, while the velocity in summer varies from 0·5 to 0·9 metre per second. We may say that the Nile in soil has a natural section whose width in flood is 110 times its depth, while its mean velocity is 1·50 metres per second.

The natural canals, which take off the river and which never silt, have

a mean velocity of some 65 centimetres per second, while the proportion of width to depth is about 12 to 1. Artificial canals of this section do not silt if their velocities are 80 centimetres per second.

To the north of Esna is the Esna Barrage, with 119 openings of 5 metres and 11·5 metres depth of water in high flood. It was first used in August 1909.

To the north of Assiut is situated the Assiut Weir or Barrage across the Nile, with 111 openings of 5 metres and 10 metres depth of water in high flood. It was regulated on for the first time in August 1902.

On Roda Island, opposite Cairo, has stood a gauge from the earliest times. It has been frequently reconstructed. The present gauge is reputed to have been erected in A.D. 861 with its zero at the same level as a more ancient one whose readings have been preserved since A.D. 641. When the gauge was constructed, a reading of 16 cubits meant the lowest level at which flood irrigation could be ensured everywhere. The level to-day is 20½ cubits on the gauge, and the difference between them is 1·22 metres. As 1026 years have elapsed since the construction of the gauge, it means a rise of 12 centimetres per 100 years. This is slightly under the rise calculated at Aswan by the French savants.

The following table gives the means of the maximum flood and low-water levels per century :—

| | R L. flood. | R.L. low water. | Difference. |
|---|---|---|---|
| 7th century . . . | 17·5 | 11·0 | 6·5 |
| 8th " . . . | 17·4 | 11·1 | 6·3 |
| 9th " . . . | 17·5 | 11·2 | 6·3 |
| 10th " . . . | 17·5 | 11·3 | 6·2 |
| 11th " . . . | 17·5 | 11·4 | 6·1 |
| 12th " . . . | 17·7 | 11·5 | 6·2 |
| 13th " . . . | 17·7 | 11·6 | 6·1 |
| 14th " . . . | 17·9 | 11·7 | 6·2 |
| 15th " . . . | 18·2 | 11·8 | 6·4 |
| 16th " . . . | 18 4 | 11·9 | 6·5 |
| 17th " . . . | 18·8 | 12·0 | 6·8 |
| 18th " . . . | 19·1 | 12·1 | 7·1 |
| 19th " . . . | 19·5 | 12·2 | 7·3 |

It is evident from the above that the head of the Delta, or the bifurcation of the Nile, was much nearer to Cairo in early days than just now, and the last three centuries have seen great changes. The fall of water surface is very considerable at every bifurcation, and the difference between mean high and low supply at the barrage to-day is 6·0 metres against 7·2 metres at Cairo. Judging from the above figures, we may say that from the seventh to the thirteenth century the bifurcation was gradually approaching Cairo, while since the thirteenth it has been receding.

The following table gives the highest and lowest floods at Cairo during periods of twenty-five years from A.D. 639 to A.D. 1904.

The gauges are in pics and kirats, and are also referred to mean sea.

TABLE 153.—CAIRO GAUGE (RODA).

| Years, A.D. | Highest Maximum. | | | Lowest Maximum. | | | Number of Years recorded. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | Pics. | Kirats. | Metres. R.L. | Pics. | Kirats. | Metres. R.L. | | |
| 639– 650 | 19 | ... | 18·16 | 14 | 21 | 16·74 | 11 years | |
| 651– 675 | 19 | 23 | 18·42 | 15 | 12 | 17·07 | 25 ,, | |
| 676– 700 | 18 | 17 | 18·08 | 13 | 6 | 15·87 | 25 ,, | |
| 701– 725 | 18 | 22 | 18·14 | 13 | 18 | 16·13 | 25 ,, | |
| 726– 750 | 18 | 13 | 18·04 | 14 | ½ | 16·28 | 25 ,, | |
| 751– 775 | 18 | 10 | 18·00 | 14 | 19 | 16·70 | 25 ,, | |
| 776– 800 | 18 | 4 | 17·93 | 14 | 1 | 16·29 | 25 ,, | |
| 801– 825 | 17 | 18 | 17·82 | 14 | 2 | 16·31 | 25 ,, | |
| 826– 850 | 17 | 12 | 17·76 | 13 | 5 | 15·85 | 25 ,, | |
| 851– 875 | 18 | 8 | 17·98 | 15 | 15 | 17·15 | 25 ,, | |
| 876– 900 | 17 | 22 | 17·86 | 14 | 22 | 16·76 | 25 ,, | |
| 901– 925 | 18 | 1 | 17·90 | 13 | 4 | 15·83 | 25 ,, | |
| 926– 950 | 19 | ... | 18·16 | 14 | 17 | 16·65 | 25 ,, | |
| 951– 975 | 18 | 5 | 17·94 | 14 | 19 | 16·60 | 24 ,, | |
| 976–1000 | 26 | 23 | 21·65 | 15 | 2 | 16·85 | 25 ,, | Max. year 999 |
| 1001–1025 | 19 | 8 | 18·25 | 14 | 9 | 16·47 | 25 ,, | |
| 1026–1050 | 18 | 6 | 17·95 | 15 | 9 | 17·01 | 25 ,, | |
| 1051–1075 | 17 | 18 | 17·71 | 12 | 3 | 15·30 | 25 ,, | Min. year 1070 |
| 1076–1100 | 18 | 16 | 18·07 | 13 | 17 | 16·11 | 24 ,, | |
| 1101–1125 | 19 | 1 | 18·17 | 16 | 12 | 17·48 | 25 ,, | |
| 1126–1150 | 18 | 18 | 18·09 | 16 | 9 | 17·45 | 24 ,, | |
| 1151–1175 | 18 | 18 | 18·09 | 15 | 1 | 16·83 | 25 ,, | |
| 1176–1200 | 18 | 14 | 18·05 | 12 | 21 | 15·68 | 25 ,, | Min. year 1199 |
| 1201–1225 | 18 | 8 | 17·98 | 15 | 7 | 16·96 | 25 ,, | |
| 1226–1250 | 18 | 8 | 17·98 | 14 | ... | 16·27 | 25 ,, | |
| 1251–1275 | 18 | 17 | 18·08 | 16 | 12 | 17·48 | 23 ,, | |
| 1276–1300 | 19 | 7 | 18·24 | 15 | 18 | 17·22 | 25 ,, | |
| 1301–1325 | 18 | 19 | 18·10 | 16 | 2 | 17·37 | 25 ,, | |
| 1326–1350 | 18 | 21 | 18·13 | 16 | 5 | 17·40 | 25 ,, | |
| 1351–1375 | 24 | ... | 20·05 | 16 | 18 | 17·55 | 24 ,, | Max. year 1359 |
| 1376–1400 | 20 | 3 | 18·46 | 16 | 13 | 17·50 | 25 ,, | |
| 1401–1425 | 20 | 12 | 18·56 | 16 | 13 | 17·50 | 24 ,, | |
| 1426–1450 | 20 | 21 | 18·67 | 15 | 7 | 16·96 | 23 ,, | |
| 1451–1475 | 18 | 8 | 17·98 | ... | ... | ... | 1 ,, | |
| 1476–1500 | 20 | 21 | 18·67 | 19 | 17 | 18·55 | 2 ,, | |
| 1501–1525 | 20 | 16 | 18·61 | 16 | ... | 17·35 | 19 ,, | |
| 1526–1550 | | | | | | | | |
| 1551–1575 | | | | | | | | |
| 1576–1600 | 26 | ... | 21·13 | 18 | 8 | 17·98 | 11 years | Max. year 1587 |
| 1601–1625 | 24 | 5 | 20·16 | 17 | 23 | 17·88 | 19 ,, | ,, 1602 |
| 1626–1650 | 19 | ... | 18·16 | 15 | ... | 16·81 | 3 ,, | |
| 1651–1675 | 22 | ... | 18·97 | ... | ... | ... | 1 ,, | Max. year 1669 |
| 1676–1700 | 24 | ... | 20·05 | 22 | ... | 18·97 | 3 ,, | ,, 1697 |

TABLE 153.—CAIRO GAUGE (*continued*).

| Years, A.D. | Highest Maximum. | | | Lowest Maximum. | | | Number of Years recorded. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | Pics. | Kirats. | Metres. R.L. | Pics. | Kirats. | Metres. R.L. | | |
| 1701–1725 | 23 | 4 | 19·60 | 16 | ... | 17·35 | 18 years | |
| 1726–1750 | 24 | 12 | 20·32 | 20 | 14 | 18·58 | 24 " | Max. year 1738 |
| 1751–1775 | 24 | 12 | 20·32 | 18 | 17 | 18·08 | 25 " | " 1756 |
| 1776–1800 | 24 | ... | 20·05 | 12 | 12 | 15·49 | 25 " | " 1779 |
| 1801–1825 | 22 | ... | 18·97 | 8 | ... | 13·14 | 3 " | Min. year 1809 |
| 1826–1850 | 24 | 9 | 20·26 | 18 | 23 | 18·15 | 25 " | Max. year 1850 |
| 1851–1875 | 26 | 12 | 21·40 | 19 | 13 | 18·30 | 25 " | " 1874 |
| 1876–1900 | 26 | 6 | 21·27 | 17 | 3 | 17·65 | 25 " | " 1878 } |
| 1901–1904 | ... | ... | 19·18 | ... | ... | 18·02 | 4 " | Min. year 1877 } |

At Aswan the Nile has a mean range of 7·90 metres between high and low supply, with a maximum of 9·80 metres and a minimum of 6·40 metres. The high supply varies between 13,200 and 6500 cubic metres per second, with a mean of 10,000 cubic metres per second, while the low supply varies between 350 and 1400 cubic metres per second with a mean of 590 cubic metres per second. September is generally the highest month, and May the lowest. The mean low water-level is at R.L. 85·00.

At Cairo the Nile has a mean range of 7·00 metres with a maximum of 9·6 metres and a minimum of 5·3 metres. The high supply varies between 12,000 and 4800 cubic metres per second, with a mean of 7600 cubic metres per second; while the low supply varies between 1300 and 250 cubic metres per second, with a mean of 500 cubic metres per second. October is the highest month and June the lowest. The mean low-water level is at R.L. 12·25.

42. **The Rosetta and Damietta Branches.**—During winter, summer, and low floods, regulation at the Delta Barrage interferes with the natural discharges of the two branches. The Damietta branch is gradually silting up and decreasing in size, while the Rosetta branch scours in high floods. The mean width of the Rosetta branch is 500 metres, and the mean area of the section in flood is 4000 square metres. The mean width of the Damietta branch is 270 metres, and the mean section 2700 square metres. The mean velocity of the floods ranges from 1·00 metre to 1·60 metres per second. In summer the branches are hermetically closed at their heads and receive only the water which filters into them from the subsoil. This in the Rosetta branch amounts to 20 cubic metres per second, and less in the Damietta branch. It may be noted here that at Cairo the girder bridge at Kasr el Nil is 403 metres between the abutments, and the smaller bridge is 178 metres, making a total width of 581 metres. The width of

the Kafr Zayat bridge on the Rosetta branch is 530 metres, while the old Benha bridge on the Damietta branch is 285 metres. The average depth of water in flood in the two branches may be taken as 7 metres.

The Barrage at the head of the Rosetta branch has 61 openings of 5 metres each, and one lock 15 metres wide and the other 12 metres. They are all open in high flood. The Damietta Barrage has 61 openings of 5 metres and one lock of 12 metres. The depth of water in a high flood is 9 metres.

Before the construction of the Barrage in the middle of the nineteenth century, the maximum discharges of the two branches at the head of the Delta were nearly the same. A little lower down, however, the Rosetta branch had considerably more water than the Damietta. About 2 kilometres below the barrage there was a branch called the Shalakan branch, which flowed from the Damietta into the Rosetta branch. About 20 kilometres below the Barrage, the Bahr Ferunia took about one-third of the total discharge of the Damietta branch and led it into the Rosetta branch. Both these were closed by Mohamed Ali, while at the same time the Bahrs Sirsawia, Baguria, Shebin, Khadrawia, Moes, Um-Salama, Bohia, and Sogair were also completely closed or provided with regulating heads, which very considerably diminished their discharge. During the time that they had been open the Damietta branch had lost water at every kilometre as it approached the sea, and though 400 metres wide at the head, it had a channel only 200 metres wide in its lower reaches. The Rosetta branch, on the other hand, received the tail waters of many Bahrs and had only one escape—the Bahr Saidi, near its tail.

The closing of so many escapes on the Damietta branch has caused it in its upper reaches to carry so much water that its tail reaches cannot carry it without having the surface of the water raised inordinately and dangerously above the level of the country. An examination of Tables 65 and 66 will show that while the Rosetta branch in its middle reaches is from 1·50 to 2·00 metres above the level of the country in a high flood, the Damietta branch is from 2·50 to 3·00 metres. They will also show how the slope in the early reaches of the Damietta branch is considerably less than that in the early reaches of the Rosetta branch, which results in the gradual silting up of the former, as already noted. The Karanain regulator at the head of the old Bahr Shebin, taking from the Damietta branch below the Bahr Ferunia, was built in 1842 by Linant Pasha, with its wing wall 60 centimetres higher than any previous flood. By 1870 the Damietta branch had risen 70 centimetres above the wing wall as measured by Linant Pasha. In 1878, though the Damietta branch was relieved by the Giza breach in the left bank of the Main Nile which drained into the Rosetta branch, the flood-water surface of the Damietta branch at Karanain was 1·50 metres above the wing wall.

North of Zifta is the Zifta Barrage with 40 openings of 5 metres each. The depth of water in high flood on the floor is 9 metres.

An earthen dam is annually thrown across the Damietta branch upstream of Damietta, and on the Rosetta branch upstream of Rosetta. These are swept away by the flood.

The maximum, minimum, and mean floods in the Rosetta branch are 6500, 2600, and 4000 cubic metres per second. In the Damietta branch they are 4600, 1300, and 2300 cubic metres per second respectively.

In connection with the branches reference should be made to paragraph 22 of CHAPTER II. and to Appendix IV. The latter gives a discharge diagram of the Rosetta and Damietta branches prepared in 1887.

## CHAPTER IV.

## *BASIN IRRIGATION* (1).

43. Basin Irrigation.—44 Basin Irrigation previous to 1889.—45. Colonel J. C. Ross's Basin Improvement Works.—46. Basin Irrigation Notes, 1896–97.—47. Basin Canal Discharges, 1892–93—48. The Basins of Upper Egypt in 1897.—49. Basin Irrigation Details in 1897.—50. Notes on the Basin Tracts during the Land Tax Adjustment Operations of 1896–97.

43. **Basin Irrigation.**—Considering the times of flood and low supply, the climate of Egypt, the turbidity of the Nile flood, and the deltaic formation of the Nile Valley, no better system than basin irrigation as practised in Egypt could possibly have been devised. If the flood had come in April and May and been followed by a burning summer, or if the actual autumn floods had been followed by the frozen winters of Europe or the warm winters of the Sudan, basin irrigation would have been a failure or a moderate success; but, given the Egyptian climate, basin irrigation has stood without a rival for 7000 years. It is the most efficacious method of utilising existing means of irrigation which the world has witnessed. It can be started by the sparsest of populations. It will support in wealth a multitude of people. King Menes made his first dyke when the Egyptian nation was in its infancy. Egypt, in Roman times, supported a population denser than that of to-day. The direct labour of cultivation is reduced to an absolute minimum.

Shakespeare's genius has crystallised the system for all time:—

> "They take the flow o' the Nile
> By certain scales in the Pyramid; they know,
> By the height, the lowness, or the mean, if dearth
> Or foison follow: the higher Nilus swells
> The more it promises: as it ebbs, the seedsman
> Upon the slime and ooze scatters his grain,
> And shortly comes to harvest."

If we cast back our view to the dawn of Egyptian history, we can picture the Nile Valley as consisting of arid plains, sand dunes, and marshy jungles, with reclaimed enclosures on all the highest lands. Every eight or ten years the valley was swept by a mighty inundation. The seeds of future success lay in the resolve of King Menes' engineers to confine their

attention to one bank of the river alone. It was the left bank of the river which history tells us was first reclaimed. A longitudinal dyke was run parallel to the stream, and cross dykes tied it to the Libyan Hills. Into these basins or compartments the turbid waters of the flood were led by natural watercourses and artificial canals and allowed to deposit their rich mud, and thoroughly saturate the soil; and meantime the whole of the right bank and the trough of the river itself were allowed to be swept by the floods. It must have been on this wild eastern bank that were conducted all the hippopotamus hunts which are crowded on the wall pictures of buildings of the early dynasties. In all probability the first six dynasties contented themselves with developing the whole of the left bank of the Nile and favoured sections of the right bank. As, however, the population increased, and with it the demand for new lands, it became necessary to reclaim the whole of the right bank of the river as well. The task now was doubly difficult, as the river had to be confined to its own trough. This masterful feat was performed by the great Pharaohs of the Twelfth Dynasty, the Amenemhats and the Usartsens, who, under the name of Sesostris, usurped the place of Menes in the imagination of the ancient world. They were too well advised to content themselves with repeating on the right bank what Menes had done on the left. By suddenly confining the river they would have exposed the low-lying lands of Memphis and Lower Egypt to disastrous inundations. To obviate this, they widened and deepened the natural channel which led to the Fayum depression in the Libyan Hills, and converted it into a powerful escape to carry off the excess waters of high floods; and so successful were they in their undertakings that the conversion of the Fayum depression into Lake Mœris was long considered by the ancient world as one of its greatest wonders. They led the flood into the depression when it was dangerously high, and provided for its return to the river when the inundation had come to an end. By this means, they ensured the lake against being at a high level during a period of flood. The gigantic dykes of entry and exit were only cut in times of emergency, and were reconstructed again at an expense of labour which even an Egyptian Pharaoh considered excessive. To understand how capable Lake Mœris was to control the floods, and turn a dangerous into a beneficial inundation, a study of Sir Hanbury Brown's *Fayum and Lake Mœris* is recommended. As years rolled on the Nile widened and built up its own trough, to which it was now confined; and eventually the time came when Lake Mœris could be dispensed with without danger. It was gradually reclaimed and converted into the Fayum with its 350,000 acres of cultivated land.

Basin irrigation holds the flood waters for some forty-five days per annum over the whole of the valley. The water is in places 3 metres deep, and in others only 30 centimetres deep, while the average depth is

about 1 metre. Now the retention of this water over the land for a period of six weeks permits of the thorough saturation of the subsoil in places where the subsoil is of proper consistency; and this water can be drawn on, in winter and summer, for maturing certain crops and growing others. It was where the subsoil gave a plentiful supply of water, and permitted of intense cultivation throughout the year, that we find all the ancient capitals of Egypt. Abydos has the finest subsoil water in the Nile Valley; Memphis has an excellent supply; while Thebes has the only good subsoil water on the whole of the right bank. Good subsoil water was to the ancient Egyptian world what the presence of a rich gold mine is to one of our new colonies.

Subsoil water supplies the link between basin and perennial irrigation. It explains the reason why modern Egypt is not satisfied with the irrigation which has come down from the remotest antiquity, but is desirous of conferring on the length and breadth of the Nile Valley those advantages which gave Abydos, Memphis, and Thebes their pre-eminence in the past. Any country which possesses rivers and streams whose waters are in flood for six weeks per annum at a suitable season of the year can betake itself to basin irrigation with more or less profit. The science of dams, weirs, and regulators has received such development during recent years that there can be no problem so difficult that it cannot be solved by experience and originality. Basin irrigation allows of the thorough development of countries whose streams have short and turbid floods which precede a fairly cool season; whether such irrigation be the stately irrigation of the Nile Valley, perfected by the science and experience of 7000 years; or the less perfect but still highly developed and river-fed tank systems of Madras; or the primitive but effective basins of Bundelkund, where the impounded water irrigates the crops on the downstream sides of the basins for one season, and then allows of the basins themselves being dried and cultivated in the next.

The Nile in high flood rises 10 metres above its bed, in a mean flood 9 metres, and in a poor flood 7½ metres. The beds of the main basin canals are about 4½ metres, and the cultivated land at the river's edge about 9 metres, above the river-bed. The basins have an average area of 7000 acres. Where the valley is narrow, they average 2000 acres each, and where it is wide 20,000 acres; while some of the tail basins are 40,000 acres in extent. Each canal has about seven or eight basins depending on it, of which the last is always the largest. There are masonry regulators at the canal heads, at each crossing of the cross banks, and at the tail escapes into the river. In the more perfect basins the canals and escapes syphon under one another and overlap and supply each other's deficiencies, so as to meet the requirements of every kind of flood which Egypt can

experience. Colonel Ross's work on the basin irrigation of Egypt is a monument of patient observation and a storehouse of information. Some of the canals, like the Sohagia, are veritable rivers, discharging 450 cubic metres per second; but a good average canal discharges 30 cubic metres per second. The largest canal has a width of 75 metres, while the average width is 9 metres. Good basin canals discharge in an average year 1 cubic metre per second per 500 acres. Forty-five days suffice for a perfect irrigation. The cost of providing basin irrigation in Egypt for basins of 10,000 acres may be taken at £3 per acre, thus made up:—Banks, £1·50; canals, £·75; masonry works, £·50; and bank protection, £·25. If the basins are under 5000 acres, the cost will be nearly double this. The annual cost of maintenance is £·10 per acre; while the lands themselves are rented at £4 per acre. In well-irrigated basins no manures are needed, and alternate crops of cereals and legumens have been reaped for centuries without the land having been exhausted in any way whatever. Where the subsoil water is good and double cropping resorted to, then manures have to be applied. This system of irrigation continued over the whole country through the times of the Pharaohs, Ptolemies, and Romans down to the Arab conquest in the seventh century A.D. The rich slime was annually renewed, and the soil retained its original fertility. At the time of the Arab conquest the whole country was cultivated—a fact testified by the dense population of the country as recorded by historians and by the countless remains of ancient towns. Between A.D. 700 and 1800 the population had dwindled from 12,000,000 to 2,000,000, and irrigation had been abandoned over the greater part of the Delta proper. About the year 1820 Mohamed Ali changed the system of irrigation in Lower Egypt, and basin irrigation was confined to Upper Egypt. In 1874 Ismail Pasha converted 250,000 acres in Upper Egypt to perennial irrigation, and this area was lost to basin irrigation, while the whole of the Fayum was made perennial. From 1874 onwards the total area irrigated by basin and flood irrigation was 1,750,000 acres, while 3,500,000 acres were perennially irrigated.

Between 1889 and 1891 the basins of Kena and Sohag Provinces were greatly improved by the late Lieut.-Colonel J. C. Ross, C.M.G., with money provided by a special loan. The completion of the Assiut Barrage on the Nile in 1902 greatly facilitated the basin irrigation of Minia and Beni Suef Provinces.

Between 1899 and 1902 the 70,000 acres of poorly irrigated land on the left bank of the Yusufi Canal in Minia Province were provided with basin banks, regulators and escapes, and turned into first-class land by Sir A. Webb. On the completion of the Aswan Reservoir in 1902, a beginning was made with the conversion to perennial irrigation of 400,000 acres of basin land in Minia, Beni Suef, and Giza Provinces. These works

were designed and executed by H. E. Ismail Pasha Sirry and Mr G. B. Ireland, and completed in 1910.

During 1907 and 1908, 35,000 acres of basin and flood irrigated land on the right bank of the Nile in Giza province, which were liable to "sharaki" or drought in every low flood, were provided with two powerful pumps, and converted to perennial irrigation. The works were designed by Mr K. E. Verschoyle, and carried out by Mr W. R. Williams.

During 1907 and 1908 a barrage was constructed across the Nile at Esna by Sir A. Webb and Mr M. Macdonald, C.M.G. The main canals of the province of Kena were put in communication with feeders taking off from above the barrage, and the lands commanded by them ensured against drought in years of low Nile.

The total area of the lands under basin and flood irrigation to-day is 1,287,000 acres, while 4,064,000 acres are perennially irrigated—making a grand total of 5,351,000 acres under cultivation.

44. **Basin Irrigation previous to 1889.**—In the first edition of this work, written in 1888, before the improvement works carried out by Lieut.-Colonel J. C. Ross, C.M.G., were undertaken, the system of basin irrigation as it then existed was thus described :—

"The delta of the Nile, from Aswan to the Mediterranean, having been formed by the gradual deposit of alluvial matter from the Nile in a state of flood, the high land is always on the river bank, and the low land near the desert. This feature is found not only along the main channel of the river, but also along its branches. The sections of the Nile Valley at Girga and Beni Suef (paragraph 12) show these features distinctly. This natural deltaic formation has been slightly modified by the artificial construction of dykes running both longitudinally with and transversely across the direction of the stream. These dykes enclose basins which are annually flooded with water during the inundations. The slopes, therefore, are not quite gradual, but in a series of terraces or steps.

Upper Egypt, with the exception of the Ibrahimia Canal system and the Fayum, is divided into basins by earthen dykes running transversely to the direction of the river, starting from its bank and reaching the desert. A dyke running parallel with the river, along its bank, encloses the basins on the river side, while the desert generally forms the fourth side. Some basins are still further divided by one or more dykes parallel to the direction of the river, in order to divide the low lands near the desert from the higher lands near the river's edge. Large communities have made further subdivisions, surrounded their property by dykes, and made private basins or enclosures which they can irrigate at will, and of which they control the water supply independently of the main basins. Almost all these basins have special canals to lead directly into them the flood waters charged with alluvium. The beds of these canals are almost midway between low Nile and ground level, *i.e.* about 3 or 4 metres below the level of country, or the same depth below ordinary flood. The canals are consequently dry during winter and summer. Many of the feeder canals have no regulating heads, but only a mass of loose stone at the take-off from the river. The heads of the canals taking from the Nile are annually closed

with earthen banks, which are cut about the 10th or 12th August, when the millet crops in the basins have been removed, and the Aswan gauge being ordinarily at $14\frac{1}{2}$ pics or R.L. 92·00 metres, the muddy flood-water can flow freely into the canals. Each system of basins depends on one or more canals for its irrigation; some of the canals are insignificant, and feed only a few basins; while some, like the Sohagia, discharging 450 cubic metres per second, are veritable rivers, and irrigate a very extended system. As the feeder canal passes each transverse dyke it is provided ordinarily with a masonry regulator, to control the amount of water entering the basins. Each system of basins possesses an escape, which allows the water, after it has deposited its alluvium and stood some forty days on the land, to flow back into the river. Wherever the desert impinges on the river bank there is a break in the system of basins. This happens very frequently on the right bank, but seldom on the left, where nearly all the cultivated land lies.

The filling of the basins begins ordinarily about the 12th August, and in the southernmost basins is completed by the 1st October, when the escapes are opened and the water discharged back into the Nile ordinarily by the 15th October. As one advances northwards the date of discharge, and consequently of emptying of

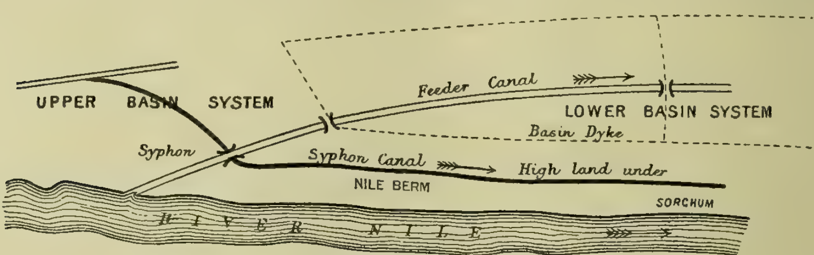



FIG. 22.

the basins, becomes later, until at the last basin north of the barrages the escape is ordinarily opened on the 11th November, and the basin dry by the 30th November. When the time of emptying the basins has arrived, if the basins have been completely filled and the Nile has fallen considerably, the escapes are opened and the water discharged. When masonry escapes do not exist the bank is cut; this breach has to be annually repaired before the next flood. If the flood has been a low one, and the basins are not quite full, wherever possible the upper series of basins is drawn on and their water discharged through the lower, thus completing the irrigation. If the Nile is still high when the time of emptying has come, there is no resource but to let the water stand in the basins till the Nile is low enough. This occurs very seldom indeed. The delay in drying the basins is said to engender worms which destroy the crops, while the delay itself puts off the ripening of the grain into the month of April, when hot winds parch the corn and make the crop a light one. The land near the banks of the Nile is so high that ordinarily the Nile cannot cover it. It is flooded eight or nine times a century, when the Aswan gauge is over $17\frac{1}{4}$ pics, or R.L. 93·50 metres. This land is planted with millets in flood, and irrigated by means of minor canals, known locally as syphon-canals, because they bring their water at a high level from an upper series of basins and pass it under the next feeder canal by a syphon.

Since the slope of the basin canals is about $\frac{1}{20,000}$, while that of the Nile is

$\frac{1}{12,900}$, and that of the country $\frac{1}{10,800}$, it takes 36½ kilometres for such a basin canal to gain 1 metre on the Nile, and 23½ kilometres to gain 1 metre on the country. These syphon or berm canals, which permit of a double crop on the high lands near the Nile (viz. millets during flood, and wheat, beans, etc., in winter), are dammed up in so many places along their course in order to raise the water surface as much as possible, that the silt deposits are enormous. The yearly clearance of these deposits is a very serious matter.

On the left bank of the Nile, from Aswan to the Ramâdi Canal head (a distance of 83 kilometres), there is but one small basin. From the Ramâdi Canal head to a point 20 kilometres north of Kena, where the desert impinges on the Nile for the last time (a distance of 220 kilometres), the basins are irrigated by three systems of canals, which are separated from one another by rocky headlands of desert, but provided with canals traversing these desert headlands. From the last desert bank to Sohag, a distance of 144 kilometres, there are two systems of basins. From Sohag to a point 100 kilometres north of Assiut, a distance of 200 kilometres, the Sohagia Canal feeds the basins. From the tail of the Sohagia Canal to Girza, a distance of 235 kilometres, the Bahr Yusuf, aided by six canals, feeds the basins; while the remaining 100 kilometres to the Barrage are fed by the Girza Canal. From Assiut northwards, on a length of 295 kilometres and an area of 250,000 acres, Ismail Pasha in 1873 took up the land corresponding to the tracts irrigated by the syphon canals and the eastern parts of the basins, dug a deep summer canal, known as the Ibrahimia, and introduced summer irrigation. The Bahr Yusuf, which used to take out of the Nile, had its head transferred to the left bank of this canal, and was thus supplied with summer water for consumption in the Fayum. Previously to this the Bahr Yusuf used to obtain its summer supply from infiltrations only. The Bahr Yusuf, after following the depression near the desert, finds at Lahun a gap in the hitherto continuous chain of Libyan Hills; it escapes through the Lahun regulator, on the line of the Lahun embankment (which does duty here for the Libyan Hills), and irrigates the province of the Fayum.

Since the slope of the country is greater than that of the Nile, it is not difficult to obtain a sufficient velocity in the canals to carry the Nile mud to the furthest parts of the basins in any well-regulated system. There are altogether 141 basins on the left bank in Upper Egypt, covering an area of 1,155,500 acres, while on the right bank there are 71 basins covering an area of 279,500 acres. There are therefore altogether 1,435,000 acres in 212 basins, with a mean area of 8200 acres per basin on the left bank, and 4000 acres per basin on the right bank; or, for the whole of Upper Egypt, a mean area per basin of 6800 acres. Of the balance, 581,500 acres are under summer irrigation on the Ibrahimia canal and in the Fayum, and 296,800 acres are under flood irrigation on the Nile berms. Two of the largest basins in Upper Egypt are Delgâwi, at the tail of the Sohagia system, and Koshêsha, at the tail of the Bahr Yusuf system; the former contains 50,000 acres, and the latter 75,400 acres.

The basin dykes have an average width at top of 6 metres, height of 3½ metres, and slope of 1 in 1; a few of the transverse dykes are pitched with stone on their northern slopes, to break the force of the waves when the basins are filled with water. Since the average depth of water is 1·50 metres on very extended areas, and Upper Egypt in flood time is like a great lake in the heart of the dry parched desert, it is common to have sudden severe winds which endanger the banks. The

villages within the basins are on artificial mounds, protected with stone ; and during flood they are so many small islands, between which communications are kept up by boats or by the dykes.

The accompanying sketch gives a general plan of an independent system of basins. A is the head of the basin canal; B is the syphon for the syphon canal; C is the high land under millet; D, E, F, G, are basins, of which the tail basin G is nearly always the largest; H, K, L, are regulators; M is the final escape over the rocky desert headland. Each basin may be assumed to be from 5000 to 15,000 acres in extent, or on an average 10 kilometres long and 4 broad.

Previous to the rise of the Nile, the basin canal is closed at its head by an earthen dam, which is cut about the 12th August. If the system is a perfect one, there is a regulating head at A, and a regulating escape at M, with regulators in the transverse banks at 1, 2, and 3. This, however, is very rare indeed. By the 12th August the Nile is high enough to enter the basin canal with great velocity, and carry its slime to the furthest basin G, all the regulators being fully open. The

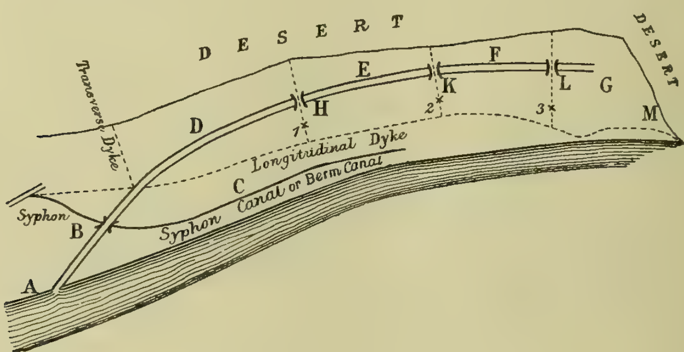



FIG. 23.

regulators are kept open until the lowest basin G is within 30 centimetres of its full supply, when the regulator L is partially closed ; and so on up the series, until the first regulator H is reached, when the filling of the first basin D is taken in hand by closing the regulator H. When the basins are empty, there is at first a severe draw at the head of the basin canal, and too great a velocity to allow of silt deposit. As the basins fill up, however, the slopes become less and less, and eventually become so small that in very many of the canals a heavy silt deposit takes place. If the canal has a discharge insufficient for the series of basins, the closing of the regulator takes place very late, and the velocity not being checked, there is no silt deposit in the canal; when, however, the canal has a sufficient discharge, the closing of the regulators causes heavy silt deposits. If the flood is an average one, the operation of filling the basins is over in forty days; that is, if the filling began on the 12th August it is over by the 22nd September; if the flood is a very high one it may be over by the 1st September; if a low one, by the 1st October. When the upper basin D is full, the canal head is closed by throwing in stone pitching if there is no regulating head; by closing the head regulator if there is one. This generally takes place about the 22nd September, though it may be over on the 1st September. The evaporation and absorption, meanwhile, which are together about 15 milli-

metres per day, and, therefore, equal to $\left(\frac{4200 \times 15}{1000} = \right)$ 63 cubic metres per acre per day, considerably reduce the quantity of water inside the basins, which quantity is made good by reduced supplies from the heads of the canals. Meanwhile the Nile is steadily falling, and very frequently the water in the first basin D becomes higher than that in the Nile. In the southern provinces the 1st October is the day to begin discharging the basins. This is a very delicate operation. The situation must first be taken in. In an ordinary year the upper basin D is full of water, the other ones are within 30 centimetres of full supply, the regulators are closed, holding up about 1·50 metres each; and the escape M is closed. Ordinarily the escape M is first opened, and then the regulators L, K, H, so that basin D is discharging more into basin E than E is into F, and basin F is discharging more into basin G than the escape M is; by this means all the basins are filled to their proper height before they are dried. Basin D is the first to be empty, and basin G is the last. As the beds of the basins gradually appear, beginning at the south and moving northwards, because the south end is always higher than the north, the sowing broadcast of the seed on the slime commences. The first basin in Upper Egypt is dry ordinarily by the 5th October, and the last by the 30th November.

This is the basin system in its simplest aspects in an ordinary, and therefore favourable, year. If the flood were always a good one, an independent basin system would always be the best, as the system is self-containing, and at the time of discharge, discharges straight into the Nile, and does not complicate matters lower down. It will be noticed, however, by referring to the sketch, that the system above this one was in communication with it; and if the flood were a bad one, the upper system was capable of sending down enough water to fill completely the basin D and flush all the other ones, and leave not a single acre unirrigated. The system below the one on the sketch is not so favourably situated; no water can pass the rocky desert at M, and, consequently, if the flood is below the average, the upper basins of the next series will not be completely filled, lacking the aid from above. The syphon canal at B, which irrigates the high lands flush, will also be an impossibility, and consequently the lands below these rocky headlands, and below the Sohagia Canal head, where there is no syphon,* are always poor and inferior. It is on account of the frequency of low Niles that systems in communication with each other are much to be preferred.

It often happens that during the filling of the basins, owing to an accident, or the failure of some regulating apparatus, one or more basins get more water into them than their proper allowance, and threaten to burst the transverse banks. This water has to be carefully distributed among the other basins. The relieving of the basins is quite a distinct operation from the final discharging. If one of the transverse banks is breached, which fortunately happens very seldom, the whole series of transverse banks may have to be breached to prevent inundations; and that means impossibility of good regulation, and heavy repairs afterwards. All these difficulties exist because there is a great lack of masonry regulators in the transverse dykes and a lamentable absence of masonry escapes. If there was a good masonry escape attached to each system of basins, surplus water could easily be disposed of; but since there is no masonry escape, as a rule, the engineers know well that once the final escape is cut there is no closing it again, and consequently have to be very

* Since remedied.

hard put to it indeed ere they cut the final bank before the proper time of discharge. With a good tail escape and ample masonry regulators in the transverse dykes, it would be possible to run the flood water though the basins during the whole flood, and thus gain much additional slime on to the lowest basins, instead of, as at present, bottling up the basins through half the flood, and letting them simmer under a hot tropical sun.

After passing a point about 20 kilometres to the north of Kena there are no places where the desert impinges on the left bank of the Nile, and the different systems of basins are in communication with each other. These basins are in principle the same as those described above, except that they all tail into one another. The two main points of escape are: Abutîg, south of Assiut, for all the basins of Girga and half those of Assiut; and Abu Kadîga, opposite the Koshêsha basin, for all the basins between the Ibrahimia Canal and the desert. Since the construction of the Ibrahimia summer canal, the basins between the tract irrigated by it and the desert, which depend for their water on the Bahr Yusuf, have never had enough of red muddy water, and many of them can only be filled at the time of discharge, for a few days, with clear water which has left its deposit elsewhere. This means great deterioration of soil. Major Hanbury Brown, Inspector of Irrigation, has been able to increase the muddy water supply by supplementary canals, taking direct from the Nile, and discharging through syphons under the Ibrahimia Canal; while Colonel Ross has left the breach in the Koshêsha basin bank open through the flood, and thus obtained for this extensive tract of land a supply of muddy water direct from the Nile, which has increased the yield of the crops fully 30 per cent. In discharging the water from this long series of basins through the Koshêsha dyke, three factors have to be considered: 1st, all the upper basins shall have been filled to their proper level; 2nd, the Koshêsha basin shall not be drowned out, and have to relieve itself into the next system of basins, and swamp it; and 3rd, the water shall not come down in a quantity and at a time inconvenient to Lower Egypt, which at this stage of the flood lies at the mercy of this basin water. The Nile at the Barrages rose 1·50 metres in thirty-six hours in October 1884, on the rupture of the Koshêsha dyke. Below Koshêsha lies the province of Giza, with a self-contained system which works well.

The problems before the engineers who have charge of basin irrigation are threefold. The first has reference to the fact that as many acres as possible should be irrigated every year so that the land tax might be assured. The second has reference to the times of filling and emptying of the basins so that full advantage might be taken of the Nile flood, and at the same time all the basins emptied and uncovered at a time eminently suited for the sowing of the winter crop. The third problem has for its solution a distribution of the red muddy waters of the Nile flood in such a manner that all the basins and every part of every basin shall have, as far as possible, its fair share of the rich deposit of mud. The last is possibly the most difficult of the three, as there is always a tendency for the sand to drop first, and then the rich mud, and finally the very finest particles of mud. If the distribution is bad, as it is on the Bahr Yusuf basins, some basins receive little but sand, others have far more than their share of rich mud, and the greater part have nothing but the finest particles of mud with a large proportion of salts; especially is this the case where white water has stood for any length of time without any perceptible flow. Good basins like those of Girga have the least of these defects.

One cannot study the principles of basin irrigation without admiring the skill and order of the whole operation. The basin irrigation of Upper Egypt, gradually developed through 5000 years, commands sincere admiration.

It will readily be understood that since the country has a slope of about $\frac{1}{10,800}$, the mean depth of water needed to cover a large basin some 15 or 20 kilometres long is much greater than that needed for a small basin some 5 kilometres long. To completely fill a basin of—

| Acres. | | Metres. | Cubic metres per acre. |
|---|---|---|---|
| From 35,000 to 45,000 | there is needed a mean depth of | $\frac{2 \cdot 5 + 1 \cdot 0}{2} = 1 \cdot 75$; | or 7350 |
| „ 25,000 „ 35,000 | | $\frac{2 \cdot 0 + 1 \cdot 0}{2} = 1 \cdot 50$; | or 6300 |
| „ 10,000 „ 25,000 | | $\frac{1 \cdot 5 + 1 \cdot 0}{2} = 1 \cdot 25$; | or 5250 |
| „ 5,000 „ 10,000 | | 1·0 = | or 4200 |
| Less than 5000 acres | | ·75 = | or 3150 |

For a healthy system the quantity should be supplied in forty days, and since 9000 acres represent an average-sized basin in Upper Egypt, the mean discharge of a feeder canal should be $\frac{4200}{40} = 105$ cubic metres per acre per day, plus evaporation and absorption 1·5 centimetres per day for forty days, or plus 63 cubic metres per day. The total discharge would therefore be 168 cubic metres per acre per day. This, however, is not always obtained. A discharge of 168 cubic metres per acre per day means 1 cubic metre per second for 660 acres. The escapes give back into the river in twenty days the water which remains in the basins after evaporation and absorption losses are deducted. After the canal heads have been shut, the full supplies into the basins are obtained by manipulation between the basins themselves. The above quantities will hold good for even the large basins, since most of them have reserved for millets large areas which are separated from the rest of the basins by subordinate dykes, and are only filled at the time of the discharge after the millet crop is off the ground. In very many of the larger basins, so late is the full supply in coming, that all the higher-lying parts of the basins are sown with millet in August, and reaped in October, before the final filling takes place. These fields are not protected by banks.

By examining the tables of basins, which give the times of discharge of each series, it will be seen that in an average year the quantities of water discharged from the basins of Upper Egypt are as follows :—

| | Acres. | | Cubic metres per day. | Cubic metres per second. |
|---|---|---|---|---|
| Kena and Esna, . | 300,000 × 143, | Oct. 1 to Oct. 20 | = 42,900,000 | or 500 |
| Girga and Assiut, . | 500,000 × 143, | Oct. 5 to Oct. 25 | = 71,500,000 | or 820 |
| Bahr Yusuf series, . | 500,000 × 143, | Oct. 15 to Nov. 5 | = 71,500,000 | or 820 |
| Giza and Rikka, . | 100,000 × 143, | Oct. 10 to Nov. 5 | = 14,300,000 | or 170 |
| | 1,400,000 | | | |

The rest is discharged into the Rosetta branch of the Nile. The supplies to

be expected in Lower Egypt in an ordinary year, taking five days from Kena, four days from Assiut, and one day from Koshêsha, are therefore:—

| | | Cubic metres per second. |
|---|---|---|
| October | 5th | 450 |
| ,, | 10th | 1200 |
| ,, | 16th | 2300 |
| ,, | 20th | 2300 |
| ,, | 26th | 1800 |
| ,, | 31st | 900 |
| November | 6th | 120 |

The discharge of the Nile at Cairo when the gauge is—

| | | | |
|---|---|---|---|
| 3 metres is* | 2130 cubic metres per day. | | |
| 4 ,, | 3100 | ,, | ,, |
| 5 ,, | 4350 | ,, | ,, |
| 6 ,, | 5850 | ,, | ,, |
| 7 ,, | 7600 | ,, | ,, |
| 8 ,, | 9800 | ,, | ,, |

When it rises

| | | | | |
|---|---|---|---|---|
| From 4 to 5 metres* | the increase is | 1250 cubic metres per day. | | |
| ,, 5 to 6 ,, | ,, | 1500 | ,, | ,, |
| ,, 6 to 7 ,, | ,, | 1750 | ,, | ,, |
| ,, 7 to 8 ,, | ,, | 2000 | ,, | ,, |

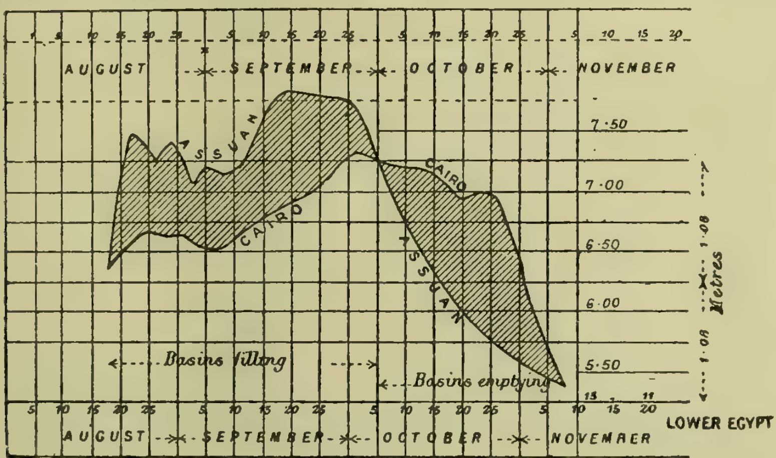
An extra discharge of 2300 cubic metres per second means, therefore, in an ordinary October when the gauges are between 6 and 7 metres, a rise of 1·20 metres. By referring to the following diagram of the Aswan and Cairo gauges for 1886, it will be seen that this rise does actually take place in October. This diagram has been prepared by making the Aswan gauge of the 1st October correspond with the Cairo gauge of the 6th October, because at that date the filling of the basins is practically completed, and the discharge not yet begun.

The gauges are also made to correspond on the 17th August and 8th November (Lower Egypt dates), and the Aswan curve *very* slightly altered between October 22nd and 8th November to allow for the Aswan water reaching Cairo in five and a half days during full flood, and in eight days at the early and late stages.

In Upper Egypt the level to which the bed of each canal is cleared is referred to the Aswan or Cairo gauge, according as it is upstream or downstream of the Koshêsha basin. This is a very practical method of understanding the canals, without the aid of levels. The Nile is so uniform in its flow during the period of filling the basins, that if it had reached a certain height at the time of filling, when the Aswan gauge was R.L. 92·00 metres, say in 1881, it will be at the same height for the same gauge in 1888. By this means the canals are cleared so as to allow them to take in water at a certain stage of the river. Formerly, they used to be cleared to a very low gauge and given slopes of $\frac{1}{50,000}$, but now they are cleared to fixed gauges, and given slopes of $\frac{1}{20,000}$, and $\frac{1}{33,333}$ in very exceptional cases in the Kena Province. By this means the silt clearance has been much reduced, without

* To find R.L., add 12·25 metres.

any appreciable loss of water, since the Nile rises very quickly at the beginning of the flood after it has once passed 8 pics or R.L. 88·50 metres at Aswan. For the Giza Province the levels are referred to the Cairo gauge, as it is close at hand and much affected by the escape water from the upper basins. Advantage has been taken of the long continuance of the flood in this province, compared to the stay in the upper provinces, to have smaller canals for filling the basins, since a good supply can always be counted on for sixty days, instead of only forty days. Owing to its lying so far north also, this delay is not prejudicial to the crops, as it would be in Esna and Kena. The readiness with which an intelligent Egyptian engineer refers every basin and canal to the inclined plane of the Nile flood starting from the Aswan gauge, is surprising to one accustomed to refer all heights to a horizontal




Zero = R.L. 12·25 m.

FIG. 24.

base, such as mean sea. In the long Nile Valley, however, to the south of Cairo, there is great wisdom in adhering to the inclined plane, if for nothing else, as an insurance against mistakes in levels."

## 45. Colonel J. C. Ross's Basin Improvement Work.

"After the above was written a great deal of literature appeared on basin irrigation, and great improvements were made in the irrigation itself. During 1886 and 1887, Colonel Ross had been carefully studying the basin systems of Egypt and preparing a scheme for remedying the more patent wants, when the low flood of 1888, followed by a loss of revenue of £300,000, induced the Egyptian Government to borrow £800,000 and devote it to the execution of works for the protection of the country from drought, known locally as 'sharâki.'"

In a note on the prevention of "sharâki" or drought in Egypt, written by Sir Colin Scott-Moncrieff on the 16th December 1888, and published by the Egyptian Government in 1889, the principle on which the works were to be carried out is very clearly stated. From it the following selection is made:—

"On the 10th November 1888, the Council of Ministers invited the Ministry of

Public Works to take into serious consideration the large area of land left year by year uncultivated for want of irrigation during the Nile flood, and the very serious loss resulting to the revenue and to the country.

It appears that after the flood of 1877 an area of 947,471 acres remained uncultivated, causing a loss of revenue of £1,111,880. In the following years up to 1887 there has been on a yearly average 45,126 acres drought, with a loss of £37,718. The returns for 1888 are not yet known, but the estimated area is 260,000 acres, with a loss of £300,000. These figures justify a close inquiry into the subject, and a large outlay to obviate the yearly loss.

In the following note I can be little more than the exponent of the views of Lieutenant-Colonel J. C. Ross, C.M.G., who has for some years past made the closest study of the irrigation system of Upper Egypt, and whose unrivalled knowledge of the subject imparts the greatest confidence in his results.

The records of this Ministry give the height to which the Nile has risen annually at Cairo throughout the last 150 years

During these years the following have been the lowest Nile floods:—

| Years. | Gauge at Cairo. metres. | Gauge at Aswan. metres. |
|---|---|---|
| 1782 | R.L. 18·00 | ? |
| 1783 | R.L. 17·95 | ? |
| 1784 | R.L. 18·05 | ? |
| 1832 | R.L. 18·15 | ? |
| 1877 | R.L. 17·65 | R.L. 91·40 |
| 1888 | R.L. 18·05 | R.L. 92·10 |

There is no record of the Nile gauge at Aswan earlier than 1869, nor of the extent of drought earlier than 1877, when the failure far exceeded any year of which we have record. It is particularly to be noticed that during three succeeding years the flood failed to attain the height of 1888. We have no right then to count on a better flood during 1889 than the last.

In years such as 1888 the water surface never overflows the valley. To inundate it, therefore, canals having bed slopes less than that of the river have been constructed, along which the water flows, until its surface is higher than that of the fields. Supposing the slope of the river to be 7½ centimetres, and of the canal 3 centimetres per kilometre, it is evident that at the end of a kilometre the water surface in the latter will be 4½ centimetres higher than in the former, and if the surface of the land is 90 centimetres higher than the water surface of the river, the water in the canal will overflow this land 20 kilometres from its head.

This principle has been fully recognised by the designers of canals in Upper Egypt. In the practical application there has been failure. From long experience the cultivator knows the level at which the water will stand opposite his lands corresponding to the surface-level at Aswan; and it has been generally accepted that the beds of the canals where they leave the river should be at such a level that water would just enter them with a 4-metre flood at Aswan. In the largest canals the beds are sometimes ½ metre lower. If this rule had been always followed, and the canals properly constructed, even in a year like 1877 there would have been 2 metres of water entering them, and as that year the water surface in the river flowed about 1·50 metres lower than the banks, if the canal surface gained on the

river $4\frac{1}{2}$ centimetres per kilometre, the water in the canal would have overflowed the lands 33·3 kilometres from its head.

This may be easily seen from the following diagram :—

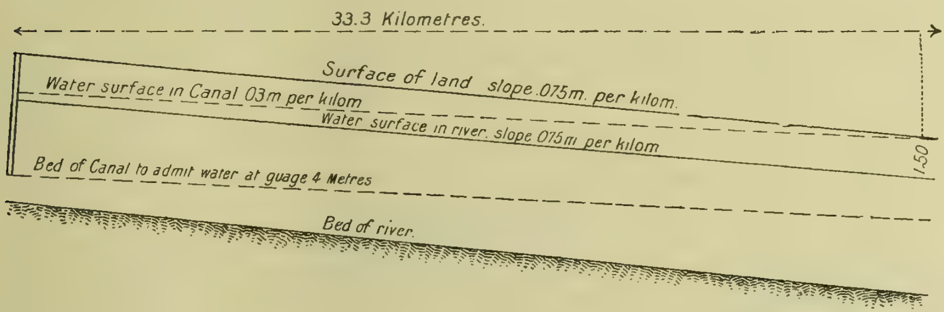



FIG. 25.

Now, to irrigate this upper 33 kilometres water must either be raised artificially or supplied from a canal taking its source 33 kilometres further up the Nile, and supposing the land to be level for the whole width of the valley, and the above slopes to be uniform, each canal would require to be 33 kilometres long before it began to irrigate in such a year as 1877; a state of things which would involve the country in enormous lengths of canals, to be made and maintained. Fortunately the circumstances are not so unfavourable. Throughout Egypt the valley is highest on the river bank. A flood then 1·50 metres lower than the bank is often at many places not more than 50 centimetres lower than the average level of the valley, which could therefore be inundated by a canal like the above only 11·12 kilometres long.

The slope of the river, moreover, is taken on its winding course, and if it is $7\frac{1}{2}$ centimetres per kilometre, the slope of the axis of the valley, parallel to which the canals generally flow, is at least 10 centimetres, so that a canal with a slope of 3 centimetres gains on the land 7 centimetres per kilometre. In a year like 1877, then, it would overflow the land near the Nile at a distance of $\frac{1·50}{·07} = 21·4$ kilometres, and would overflow the most of the valley at a distance of about 10 kilometres from the head. Such a year as 1877 probably does not occur once in a century. In 1888 the water surface in the river stood about 1 metre below the river bank or berm, and assuming slopes as above had the canals been in thorough order, they would have begun to overflow the river bank or berm at $\frac{1·00}{·07} = 14·3$ kilometres, and the lower parts of the valley soon after entering the canal. Even in such a year as 1877, then, it would be possible to irrigate the whole area of the valley, provided the canals were all in good order, one overlapping the other. The only obstacle to this system of overlapping is that at certain places known as *Mahgars* or cliffs, especially on the eastern bank, the desert hills come right to the river edge and interrupt the series of canals. Immediately downstream of an impassable cliff the land can only be submerged in favourable years when the Nile is as high as R.L. 92·75 metres at Aswan. In years of less flood the water must be raised artificially. On the east bank the cliffs conveniently divide the Nile Valley into systems of basins,

of which there are eight to the south of Manfalut in the province of Assiut. From this point northwards to opposite Wasta there is a series of detached parcels of land separated by impassable cliffs. North of Wasta is a series of basins extending to the vicinity of Cairo.

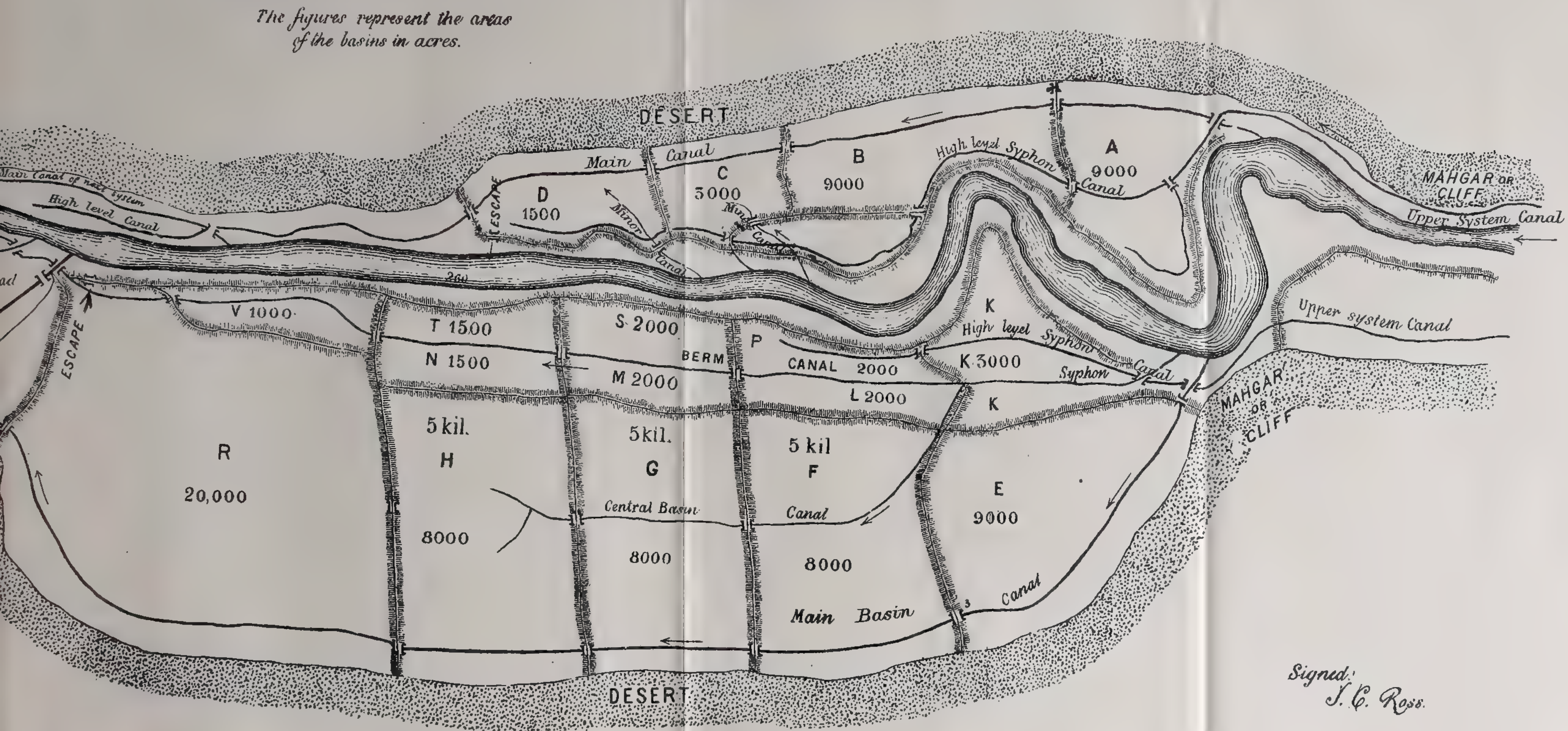
On the west bank there are two cliffs both passed by canals opposite Karnak, and near Dendara. North of this is an extensive system extending to Assiut. From Assiut to south of Wasta the system of basins to the west of the Ibrahimia Canal must be considered as under special conditions. From Wasta to the northern limit of Giza is one long system in a condition by no means satisfactory. The systems are at present in every stage. In some the necessary works are nearly finished, in others they hardly exist.

During the Nile flood two quite different sorts of irrigation go on in Upper Egypt. The Nile Valley is divided into great basins, and, generally speaking, when the river rises nothing is growing in them. These basins are flooded to a mean depth of perhaps 1 metre, and it is not until the water has been run off them by the operation known as *sarf*, or discharge, that the land is sown with the cereal crop which ripens during the following spring. But parts of these basins, especially the Nile berm and higher lands, are under crops, sugar-cane, maize or vegetables, when the river rises, and these require water in moderate and regulated quantities unlike the flooding of the ordinary basin. These flood crops in some districts form a very important part of the year's produce. The basins can only be flooded by the free flow of the water. The flood crop may be irrigated by water-raising machinery when the Nile is too low to cover the land. Plate XXIX. has been prepared by Colonel Ross, and shows for each side of the river a typical system of basins with its canals, embankments, and masonry works. It will be seen, beginning on the east side, that a high-level canal carried past the cliff irrigates the high berm bordering the river. All this irrigation is flood sorghum, and in years of very good Nile flood this high-level canal would not be wanted at all, as the irrigation downstream of the cliff could be done directly from the river. On the other hand, in years of defective flood, this high-level canal is the only source of irrigation for the basin A and partly of B, and in such years the flood sorghum irrigation will be extensive.

The main canal of the right bank system is taken from the river just downstream of the cliff, passes the high-level canal by a syphon, and flows northward parallel to the axis of the valley. Its waters flow freely over C and D, and if the flood is good, over B and part of A. It is carried round the next cliff, and there forms the high-level canal. The masonry works required in this system are a syphon to pass the high-level canal near its head under the main canal, bridges fitted with regulating apparatus where the different canals pass the embankments between basins, and an escape weir at the tail of the system just above the next cliff, by which to return surplus water back into the river. Many of these works already exist. The several canals should be maintained at a proper slope and section, and in order that, when the floods are favourable, the rich muddy water may freely enter the basins, *sayyalas*, or minor canals, should be cut from the river direct into them, and these should be supplied with regulators to control the water. In years of deficient flood they would be entirely closed to keep the water inside from escaping by them back into the river. The beds of these minor canals may be a metre higher than those of the larger canals, as they will only come into use in years of good flood.

GENERALISED MAP OF TWO SYSTEMS OF BASINS & CANALS UPPER EGYPT

PLATE XXIX.



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Turning to the left or west river bank, there is the same high-level canal from the upper system carried past the clift, which irrigates the berm basins K, P and L, as well as the large basin E in years when it cannot be flooded direct from the river. From the head of the system start two canals, one following the berm and irrigating a large series of basins which may be partly under flood crops, and the prolongation of this canal fed by the surplus water of the basins will be carried past the next cliff and form the high-level canal of the next system. Where the valley is wide, as in this diagram, this berm canal may throw off a branch to its left to take muddy water direct into the centre of the basins. The other main canal is shown passing along under the desert slopes, and this is the main channel of supply for all the basins F, G, H, R. In bad years R will only be supplied by the discharge from the upper basins.

For this system two syphons will be required near the head, a regulating bridge for the main canal, an escape weir back into the river under the tail of the system. Bridges (of which many exist) are also required where the canals pass from basin to basin. In nearly all the systems the canals require to be extended, and in some cases to be enlarged.

In the following table a forecast is given of the works necessary and their cost in order to secure Egypt from drought. It does not include provision for the bridges required on the embankments, of which a complete list cannot be given. Year by year some are added to their numbers, and although they are all necessary for the complete working of the basin irrigation, they are not all required immediately, their place being taken by cuts in the banks yearly filled up and re-opened. Time has not yet allowed Lieutenant-Colonel Ross to make more than a forecast for the whole work to be done. He believes it, however, ample.

Going into details, it is to be observed first the total sum arrived at is composed as follows:—

| | |
|---|---|
| Masonry works | £228,030 |
| New embankments (31 kilometres) | 11,600 |
| Extensions of canals (584 kilometres) | 305,319 |
| Widening and deepening existing canals (476·5 kilometres) | 250,690 |
| Total | 795,639 |
| Add for Personnel 5 per cent. and contingencies | 39,285 |
| Total | 834,924 |

In general the works in this list are not individually of great size or importance. The following are exceptions.

Colonel Ross proposes to build a head for the Kasra Canal (Girga) consisting of 8 openings of 3 metres, and to pass a second canal by a syphon below its flooring. The cost of this work is £10,991.

A very large and important syphon is proposed below the great Sohagia Canal close to its head. This will cost £15,871.

Further down the same canal, near the village of Enebis, where H.E. the Public Works Minister placed a dam across the canal during last flood, it is proposed to build a regulating bridge of twenty arches, to cost £10,000.*

* Instead of carrying out this work Colonel Ross made the Tahta Canal.

A similar regulating bridge, which has long been discussed, is proposed for the Bahr Yusuf in the province of Minia. It will have twenty-five arches, and cost £15,000.

The long-proposed escape for the Koshêsha basin, where year by year the Abu Kadiga bank is cut and re-made, is estimated here at £40,000. This work was first included in the Million Estimate, but funds failed to carry it out."

The principles on which the re-modelling was carried out were thus described by Colonel Ross himself in his monumental work entitled *Notes on the Distribution of Water in Upper Egypt.* The work was printed by the Egyptian Government in 1892.

"The works designed to prevent drought in Upper Egypt have nothing new in type about them. The large expenditure from loan funds has been incurred to make the whole of Upper Egypt (where economically feasible) practically independent of a low Nile, and to make each system (as far as it is economically possible) enjoy the same advantages as the others.

There are of course parts where the land is so narrow that it would not pay to bring a long canal whose head is 32 kilometres to the south through rocks and sand. Thus the left bank of the Nile from Gebel-es-Silsila to the head of the Kilabîa Canal comes under this category.

*The works necessary to prevent drought are as follows*:—

1. Digging the high-level syphon canal so as to carry the water of the southern canal, red (muddy), into the next system and flowing with a proper velocity.

2. Passing this southern canal, protected on both banks, through the southern system's basin so that the white water of the southern basin may not mingle with the red water of the canal passing through the desert headland.

3. Building syphons to pass the high-level water under the canal or canals taking off direct from the Nile at the head of the system whose southern part is irrigated by the high-level canal water.

4. Deepening the canals taking from the Nile so that they may, with a low Nile of $13\frac{1}{2}\frac{9}{4}$ cubits average, or R.L. 91·60 metres, in the latter part of August and in the month of September, deliver water at the rate of 100 cubic metres per diem per acre for the basins which they fill.

It is, of course, found that when the canals are enlarged to deliver this large supply, they will deliver far too much water in ordinary Niles. All the other works—such as canals and minor canal heads, regulating bridges in basins, escapes on to the Nile—follow as precautionary measures. By their proper use we can take into the systems at least two-and-a-half times the amount of water admitted in a low Nile, and thus very largely increase the supply of fertilising mud.

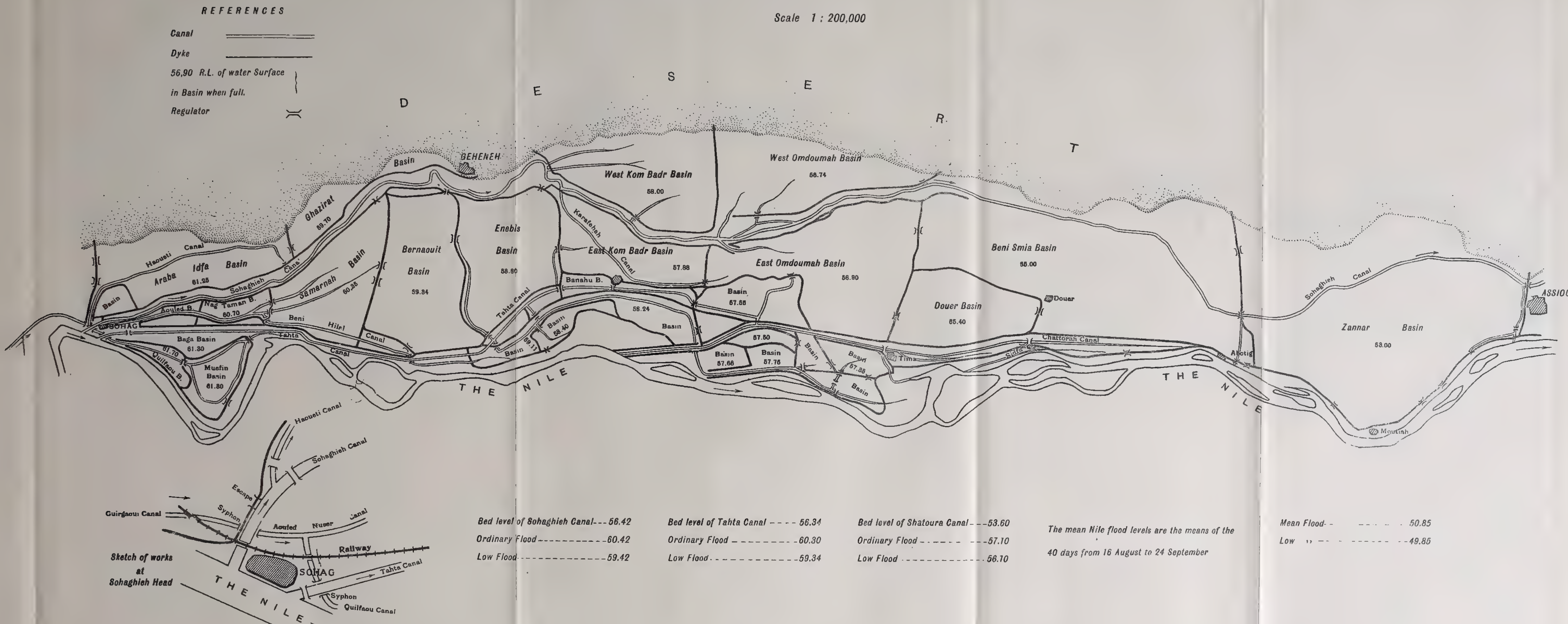
The only real departures made from the old native regime (which had its syphons, high-level canals, and regulating bridges and escapes to a somewhat limited extent) are:—

1. Circulation of good red water down the high-level canals during the whole of the Nile flood, and not (as was the ancient custom) passing white water from the southern basins after they were filled or at the time of discharge.

2. Carrying the canals which feed the basins along the edge of the Nile or in the middle of the basins in a deep channel. The old style was to pass the canal

# THE NORTH SOHAG SYSTEM of BASINS

Scale 1 : 200,000




*To face p. 316.* Willcocks and Craig Egyptian Irrigation.

down the low lands of the basin, filling the last basin first, and then gradually damming the regulators in succession to the south. Under this system the upper half of a basin was irrigated by the slow rise of shallow water through weeds, etc., and the mud remained in the low lands. On the new system the mass of red water flowing along the high land is delivered simultaneously into each basin at many points, thus equalising and increasing the red water distribution.

3. Excavation of Government minor feeders which have regulating heads and which irrigate the lands under flood sorghum in their upper reaches. On the old system these minor canals generally stopped in the sorghum tracts and had no outlet into the basin. On the new system an excess of water is carried in the minor canal and thrown off into the basin beyond by a masonry work in the bank separating the sorghum tract from the basin.

4. Removal of all regulators in the supply canals by the damming of which the flow might be arrested in the first 25 to 32 kilometres. In the old regime, after 8th September these regulators, generally situated at the 16th kilometre, used to be dammed to raise the water to a high level by reduction of slope, and thus large deposits of silt were thrown down in the first 10 kilometres and the irrigation below thrown into confusion.

*The phrases* '*Low Nile* of $13\frac{19}{24}$ cubits or R.L. 91·60 metres,' '*Mean Nile* of $15\frac{10}{24}$ cubits or R.L. 92·50 metres,' '*High Nile* of $16\frac{6}{24}$ cubits or R.L. 93·00 metres,' are used to denote certain averages of the height of the Nile at Aswan, to which gauge the figures are referred. The figures are taken from a study of about eighteen years' records at Aswan. As most canals are not opened till the 15th August on account of the summer sorghum in the basins, the actual duration of a flood is taken to be forty days, or sixteen in August and twenty-four in September. *As the low Nile calculations are made on* 100 *cubic metres per diem on each acre covered*, *including evaporation*, it follows that as an acre is 4200 square metres, the depth delivered is a little under 1 metre per acre including evaporation. This is not sufficient for complete flooding, which requires one-fourth more in the forty days.

The reduced mean sea-level is only used in Upper Egypt by the engineers when grading canals, etc., and on maps. The people and the engineers also all think in cubits. Thus in a Nile berm not protected, or an island, everyone says, that island is not covered till $16\frac{1}{2}$ cubits (R.L. 93·00 metres). All this comes from observation, and it is the most convenient way of expression. For the Nile in flood is nothing more than a large canal whose volume is being constantly diminished by the offtake of the canals into the basins.

It follows from this that the August 8 metres at, say, Girga when the canals are taking off full supply is very different from the middle of September 8 metres there. There is a distinct rise of the Nile, and in many cases the R.L. 93·00 metres of September are found to be 25 centimetres higher than the August R.L. 93·00 metres. But in the calculation for discharge and statements of rise of the Nile at mean Nile, etc., detailed in each system, the figures always refer to the Nile in August, not in September.

The canal levels are fixed at their heads at 8, 9, 10, or 11 cubits or R.L. 88·50 metres, R.L. 89·00 metres, R.L. 89·50 metres, and R.L. 90·00 metres. Similarly in the course of a canal the branch canals and minor canals are referred to as having their heads at 11 or 12 cubits of the parent canal, or R.L. 90·00 and R.L. 90·50 metres.

On this grading the height of the low Nile is assumed to be 0·50 metre below the observed highest flush of 1888, which was R.L. 92·00 metres at Aswan. This gauge of R.L. 91·50 metres is the average of the forty days of 1888. Mean Nile is assumed to be 1 metre above low Nile, and is not much verified. It is called R.L. 92·50 metres. The high Nile is assumed to be 1·50 metres above low Nile, and is called R.L. 93·00 metres.

The observations made in 1888 on the flush of 24th August at Aswan, have been each year verified on upwards of twenty-five Nile gauges between the head of the Ramâdi Canal and Assiut, and various corrections made due to original errors of observations, or lowering of the flood level due to excess of offtake from the river by the enlarged canals.

Each canal head has a Bench Mark to which it is referred.

The dimensions and levels given to the first reach of a canal must be most rigidly adhered to, as neglect of clearance of the first reach is most fatal in a bad year.

*The recent remission of revenue in the province of Kena* has given an enormous impulse to the cultivation of sugar-cane from wells, and the people in the Bayadîa, Shanhurîa and Ghilâsi systems on the east, and in the Fâdilîa and Sâhil Farshût systems on the west, are clamorous for areas protected from flood. Their demands cannot be complied with fast enough, and it will take some years before their minor canals can be brought up to the standard of the Farshût canals, with head and tail works so necessary for the proper passage of red water.

In the province of Girga also, in the Khîyâm system, there is a great awakening and investment of capital in sugar-cane. Also in the Beni Hîmêl east and Khalafîa basins, and the land on the Zarzurîa Canal down to Menshîa, the people are about to start mills. In the North Sohâg system there is not much stirring.

I again here draw attention to the great necessity of a scientific and well-thought-out delivery of the future summer supply from the reservoirs. I again protest against the folly of dislocating the entire system of Nile berm irrigation, by leading deep perennial canals through the finest and oldest parts.

For the past ten years, *the drainage of the basins* after the discharge has not been looked after much, but in the last three years increasing attention has been called to it. The local engineers have been in the habit of considering that a hollow which does not drain away, when the water retires, must be treated as a natural state of affairs. The people themselves generally relegate the drainage expenditure when proposed in council to the works to be executed, if there is money to spare.

I believe myself that these hollows, which are often 30 centimetres below the surrounding land, arise from the silting in of the land around them, owing to a better delivery of red water. In 1892, much attention has been paid to this matter and the existence of considerable areas been brought to light, in which the sowing is commonly twenty to thirty days later than the surrounding land and where, in a year like 1890, when the Nile retired very slowly, snipe have been seen in December. The principal of these hollows lie in hods Bardîs, Birbâ, 'Arâbâ, Sohâg in the South Sohâg system, and Samârna, Banawît, 'Enebis, Kom Badr east, and Um Duma east basins in the North Sohâg system.

In future, the 'Masfa,' or channel for draining the water, should be maintained wide and fairly deep. These channels need not destroy land. They may be

1 metre deep and 3 to 4 metres wide. The earth is thrown out flat, not in the form of a bank; and bed, berm, and bank are all culturable. Their inspection and clearance should be annually put in the 'Gadwal,' or list of works of the Agricultural Council.

The top of the bank is generally 5 metres wide, to allow camels laden with durra or cotton stalks to pass each other.

*The general section for slopes* is $\frac{3}{2}$ on the southern side of the cross bank, and $\frac{2}{1}$ on the northern side. Similarly on the longitudinal bank the $\frac{2}{1}$ slope is put on the side next the great basin and the $\frac{3}{2}$ on the side of the smaller basin or sorghum tract. In the Nile bank the $\frac{2}{1}$ slope is on the river side. I do not see the necessity of having $\frac{2}{1}$ slopes on both sides, except where a large basin has its bank as the Nile bank. When sorghum is permanent the slope next the sorghum is only $\frac{1}{1}$. The repairs to banks are much less in proportion in the southern systems where the water in the basins is shallow. The basins in the northern systems are much deeper, and a large amount of repairs is required every year owing to the loss from wave action. For some years past the work *of pitching the banks* has been going on slowly. The pitching is done with stone in blocks of from $\frac{3}{4}$ to $1\frac{1}{2}$ cwt. each in weight, and the interstices filled in with smaller stones and chips. The result is not altogether satisfactory. The waves dashing up against the stone force water into the crevices, and the spray is dashed up over the top of the stones and the water trickles down behind. This causes the removal of the bank from behind the stones and settlement occurs, and the waves then overtop the revetment and destroy the bank.

In my opinion, an experiment should be tried of building the coarse native masonry walls. There are many walls standing which have never been repaired, which are at least twenty years old. By using the native mortar, composed of lime and black mud from the lower parts of the basins, and the village brick burnt on the spot with durra stalks, the work would probably come to twice as much as the cost of reveting with stone, but it is far more durable, and is free from the incessant repairs necessary on the stone-faced banks.

It is a matter of great importance to have the red water of a canal which traverses the edge of the basin protected from the basin. But in many cases we have not enough money to make up the two banks. In other cases the maintenance of the made-up bank would be too expensive.

The main idea of *this submerged bank* is to have a regular channel for the low Nile water, so that before the basin reaches full irrigation level the water may flow without mingling with the white water of the basin. From observations during the Nile flood, I am confident that this submerged bank, even when beaten down by the wash of the water to a mere glacis, will give good results.

But I have observed that in cases where the excavated portion of the canal bears a too small proportion to the depth of the basin in the canal bed, there is an effort made by nature to fill in the canal with silt and reduce to a wide flat trench.

In the whole of the systems under consideration *the clearance of the canals* is the most important thing, and once that its final dimensions have been fixed, there should only be a margin of 20 centimetres allowed in the depth of silt on the bed, and a difference of $\frac{1}{20}$th in the width.

It is, of course, quite impossible that these immense canals should be trimmed and their slopes kept in order like a railway bank, but the most watchful attention

should be paid to the wetted perimeter of the low Nile section, *i.e.* up to a height of 3 vertical metres above true bed-level, when the bed is on R.L. 88·5 metres Aswan gauge. Above this it does not matter much.

The constant tendency of the upper part of the interior slope is to become flatter than $\frac{1}{1}$, and any deposit the water may lay down on it often slides off after the water has retired. There are also (owing to the immense masses of silt piled up over the slopes, which cannot be removed owing to the great expense of removal) great slips into the canal of portions of the bank. These masses, although they do not diminish the profile of the canal much, act most harmfully in deviating the current and turning it on to the opposite bank, where another slip is the result, and in the end, if these slips are neglected, the canal becomes tortuous and a swinging motion is set up in the current, which brings on banks of silt alternately right and left.

These obstructions in the side slope are often produced by the people digging irrigation wells in the canal bed and carelessly throwing their spoil on one side. These masses of hard subsoil earth are very seldom removed.

It would be well for the subordinate engineers to exercise increasing vigilance over this matter down to the 15th kilometre of each canal of supply. Below the 15th kilometre an obstruction is not of so much consequence.

As from the above observations the side slopes of a canal are very irregular, and no definite slope, such as $\frac{1}{1}$ or $\frac{3}{2}$, etc., can be laid down, it has become the custom of late years to clean the canal whenever there is less silt than half a metre or so to a rectangular section with no side slope. In some cases the theoretical width is increased by $\frac{1}{4}$ metre on each side.

The small vertical-sided piece of earth on the toe of the side slope sinks down when the water comes, and is distributed in the angle by the water and is no obstruction whatever. The facility of calculation in contract work and avoidance of quarrels about paring slopes render this method of clearance the best that can be adopted. It is termed 'Sandûq,' or box fashion, by the natives. This method is also extensively in use in the Delta.

Every year efforts should be made *to straighten the great canals* of Upper Egypt when their inside slopes are not parallel to the general axis. This straightening does not mean a real rectification of unnecessary curves in original alignment, but the removal of the numerous small internal bosses from the inner slopes. The velocity of the current is very greatly improved.

The main point to which the observation of the engineer should be directed is to find out what causes some canals to silt more at their heads than others.

For *this question of silting up at the head* is not merely one of expense in clearance, but the vital question of continuity of supply is involved. Thus all canals on a R.L. 89·0 metre gauge have, when the bed is clear, a depth of $2\frac{1}{2}$ metres on their beds in the middle of August when Aswan is at R.L. 91·5 metres.

If one silts up by 15th September half a metre, and the other $1\frac{1}{2}$ metres (no uncommon case), then the first one will, if the Nile falls rapidly by the 15th September to R.L. 92·0 metres, have 1 metre of water less than the other to finish up the irrigation. In other words, the canal that has 1·50 metres of silt on its head will not be able to maintain its middle reaches full, and damming up will have to be resorted to, and probably the middle reach high-level basins dependent on the canal will be slightly uncovered.

I find from observation of the practice of the Arab engineers that they aligned their canals under the following rules:—

1. The offtake shall be taken off the deep water of the Nile when it is running along the bank from which the canal is taken, and the canal axis shall be as nearly as possible a tangent to the general curved sweep of the Nile's central current in the curved reach. To get this they have at a great cost of labour changed the head of the Kasra Canal, of the Shanhurîa Canal and the Ma'annâ Canal.

2. When the canal must be taken from a straight reach to irrigate the Nile berm, they take it off at a very acute angle to the Nile's axis.

3. They attach much importance to having deep water in the Nile at the offtake, and are always ready to abandon any canal head that takes off a point in the Nile where a sandbank is forming. I consider that they find from experience that the coarse sand which rolls along the bottom of the Nile bed does not enter the canal unless the Nile bed has become silted up by a sandbank to nearly the level of the canal bed. This coarse sand, of course, is most fatal to the permanence of supply, as it falls within the first 50 metres on entering the canal.

Of late years these unwritten maxims have been departed from, and we have had to grapple with the difficulties of canals taking off at angles varying from 45° to even 80°.

In many canals an immense silt bank forms on the southern edge inside the canal at the offtake which, before measures were taken to prevent it, used to encumber upwards of 60 per cent. of the canal profile.

This caused a rush of water through the remainder of the canal profile, and when the bed was of stronger earth than the northern slope, the slope gave way, and a short bend was formed which set up the swinging action down the canal and caused the formation of alternate sandbanks right and left, or *vice versa*, which checked the velocity and threw down silt.

A remedy has been found in revetting the canal offtake with loose stones in such a way that the upstream side is curved and retired a few metres from the downstream side (upstream and downstream are used as regards the Nile, and are generally among the natives called south and north).

The downstream side is prolonged into the Nile in the form of a spur.

(*N.B.*—This method is in use at the Ibrahimia Canal offtake and has been very successful there.) The water then cannot attack the northern slope, and passes into the canal with a minimum of swing in the current.

These remarks about the offtake of canals apply with equal force to those canals which have masonry heads. Owing to the changing of the course of the Nile it is not safe to build the masonry head immediately on the river edge. They are in nearly all cases retired from 200 to 500 metres from the offtake.

As many of the observations on silt, etc., have to be made in the winter when the canals are dry, it is proper to note here that the upper 5 to 7 centimetres of a canal are not due to the low velocity of the Nile supply entering the canal. For at the end of September, when the basins are full and discharge is about to begin, and after discharge has commenced, the canals are shut down at their masonry heads or by bars of stone thrown in at a considerable distance from their offtake. And even below the point of damming off, the canal continues to flow for many days with a greatly checked velocity. Hence the visible top stratum in the cold weather is a very fine mud which is altogether a false index of the velocity of the

canal in the Nile flood. On removing this mud it is seen that it generally lies unconformably on a fine grey sand whose coarseness varies in proportion to the velocity of the canal in the Nile time.

*The inspection and repairs* of the lower parts *of the masonry works* in Upper Egypt are more easily carried out than in the Delta. For in the Delta the floors are always covered with water, and an expensive dam has always to be made to lay the floor dry. In Upper Egypt all the works are quite dry enough for observation by the end of February, except a few of the regulators in low lands, and thus any repairs can be effected at leisure.

The chief cause, and in reality I believe the only cause, of the gradual breaking up of the regulators of Upper Egypt is the gradual displacement or destruction of the work by the shock of the falling water.

The differences of water-level that the works have to sustain are so slight, seldom being more than 1·5 metres, that real undermining from 'creep' under the foundations is practically unknown.

In the Delta, on the other hand, the works are often exposed to differences of level of 3 metres. To avoid the danger of 'creep' the Arab engineers used to design with extremely long horizontal floors. They had no steam pumping apparatus, and could not therefore make massive curtain walls; nor did they, like the Hindus, use well blocks for foundations. So the long floor was their safeguard, and I believe that from long tradition they considered that 2 metres was the maximum head that a work would stand for any length of time. This is borne out by the fact that before 1884 the regulators at the end of the Delta main canals, which used to dam the fresh water from the salt water, were never used with these great heads, but an earthen dam was made upstream with incredible labour by the corvée.

In my opinion, the Delta design of the long horizontal floor prolonged beyond the wing walls, and no curtain, was employed in Upper Egypt, though in most cases a curtain of 3 metres was possible with a very little ordinary baling by hand.

In building, however, they omitted the downstream wing wall, and to preserve the bank from the whirlpool downstream they built a wall often 50 metres long parallel to the bank axis on the foot of the downstream slope.

Pitching with loose material was practically not used, as the art of quarrying and removal of blocks over 100 lbs. (1 kantar) was practically lost, and even to this day the contractors do not quarry in the southern parts, but merely pick up the concretionary blocks that have fallen from the mountain slopes.

The water attacks a work thus designed in the following way:—

1. By the plunging water, from between the vertical needles of regulation, eating away the bricks and lime, and thus in the end making a hole in the floor under the arch.

2. By the water, when the bridge was thrown open for discharge, plunging on to the downstream prolonged floor and curling round its edge, excavating the whirlpool close up to the edge. The floor was finally undermined backwards and fell off in blocks of 1 to 2 metres cube and sank into the pool.

3. The long wing wall was undermined by the whirlpool produced by the great rush of the water along the floor, and also by the action of the corvée, who frequently dug borrow pits close to its foot.

Finally, as the result of this constant decay of the bridge, the work was declared

'sick,' and earthed up and abandoned. In some cases too soon, for by the addition of a very small curtain upstream and the repairs of the eroded holes, and by the joining up into solid masses the broken floor downstream, several old abandoned bridges have been brought into use again.

Now in the future we can, by a more frequent and regularised inspection, and by allotting a sum of money for these repairs yearly, which should not be diverted to building new bridges, etc., almost guarantee that the bridge shall not be destroyed piecemeal.

There then only remains the real danger to be fought against, viz. the violent action of the water when more water is run through the bridge than was intended by the designer.

*The ordinary new pattern bridges* in Upper Egypt may be roughly classed as those which have 5, $4\frac{1}{2}$, or 4 metres of water on the floor on the upstream side of the regulating apparatus.

The normal conditions of use of a bridge in a basin are that there is a difference of water-level between the upstream side and the downstream side of 1 metre, and that this metre remains constant for many days, even while the basins are being emptied. The floor under the arch is horizontal, and on the same level as the floor on the upstream side of the grooves.

Taking the $4\frac{1}{2}$-metres water depth as a standard, and allowing 24 cubic metres per second per arch to be the maximum permissible, we find that when there are four planks of 0·25 metre depth resting on the floor in the grooves, the discharge is 24 cubic metres per arch of 3 metres.

In a 5-metre water depth six planks should be in, and for the 4-metre depth two planks.

Table 154 has been prepared to show the number of planks to be put in a regulating bridge to give per arch:

24 cubic metres per second;
18 cubic metres per second;
12 cubic metres per second;

with heads varying from 0·50 to 2 metres.

*Example*:—

The Hamad escape of five arches of 3 metres with full supply, R.L. 70·50 and floor upstream R.L. 65·50, is required to pass its full calculated discharge of 120 cubic metres per second. The head or difference between the river and the basin is 2 metres. How many planks should be in the grooves?

The escape has 70·50 − 65·50 = 5 metres water upstream of groove. Therefore under the 5-metre depth in the 24 cubic metres discharge table, the figure 10 is found, and therefore ten planks should be in each arch.

*N.B.*—A plank is always reckoned 0·25 metre high. They are all made to this standard now.

*It will be necessary for the Cairo authorities to give an alarm to the engineers of Upper Egypt when, according to certain indications, a low Nile is about to happen.*

For there are certain works of a precautionary nature to be undertaken for the storage of water, such as shutting certain regulators in a chain of basins with earth so as to store the water in the centre of the chain. Many isolated escapes also should be shut with earth. These works are to be done by the Nile watchers, who turn out about 10th August ready for the opening of the canal heads.

TABLE 154.—SHOWING THE NUMBER OF PLANKS TO BE INSERTED IN EACH ARCH OF 3 METRES OF A REGULATOR OR ESCAPE TO GIVE DISCHARGES FROM 24 TO 12 CUBIC METRES PER SECOND, AND FOR DEPTHS OF WATER UPSTREAM OF THE GROOVE VARYING FROM 5 TO $3\frac{1}{2}$ METRES.

| Head of Water in metres . | 0·50 Head. | | | | 1·00 Head. | | | | 1·50 Head. | | | | 2·00 Head. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | metres. | | | | metres. | | | | metres. | | | | metres. | | | |
| Depth upstream of groove | 5 | $4\frac{1}{2}$ | 4 | $3\frac{1}{2}$ | 5 | $4\frac{1}{2}$ | 4 | $3\frac{1}{2}$ | 5 | $4\frac{1}{2}$ | 4 | $3\frac{1}{2}$ | 5 | $4\frac{1}{2}$ | 4 | $3\frac{1}{2}$ |
| To discharge 24 cubic metres per second per arch. | | | | | | | | | | | | | | | | |
| No. of planks in grooves | 1 | open | too small | too small | 6 | 4 | 2 | open | 8 | 7 | 4 | 3 | 10 | 8 | 6 | 4 |
| To discharge 18 cubic metres per second per arch. | | | | | | | | | | | | | | | | |
| No. of planks in grooves | 4 | 2 | open | too small | 8 | 6 | 4 | 2 | 10 | 8 | 6 | 4 | 11 | 9 | 8 | 6 |
| To discharge 12 cubic metres per second per arch. | | | | | | | | | | | | | | | | |
| No. of planks in grooves | 7 | 5 | 3 | 1 | 10 | 8 | 6 | 4 | 12 | 10 | 8 | 6 | 13 | 11 | 9 | 7 |

To enable the Ministry in Cairo to declare with confidence a bad Nile before the end of August, it must be distinctly understood that, should the Nile rise in September to mean level or higher, there can arise no difficulty in making the change from low Nile distribution to mean Nile distribution. All that is necessary is to remove one or two planks from in front of the earthen dam which rests on them. The earthen dam will rapidly crumble away from the rush of water over it, and the regulators, etc., which have been closed with earth will, as usual, be worked for the relief of the basins and passage of water forward.

The rules I would lay down for the Cairo Ministry are thus:—

1. If on 15th August the Nile is below 13 cubits Aswan or R.L. 91·20 metres,
2. " 22nd " 14 " 91·70 "
3. " 28th " 15 " 92·20 "

the bad Nile should be declared.

The declaration should be made by telegraph to the Governors of Assiut, Girga, and Kena, and to the Inspectors and Directors of Circles, who will at once transmit the news by telegraph to all District engineers under them.

From my experience of Upper Egypt, I feel certain that the people will not be alarmed, but only get alive early to the necessity of sowing more flood sorghum. In fact now, from want of confidence in the authorities, they frequently have panics, and when the Nile does not come on by rapid rises about August 6th–12th, or when it drops or stands still about August 20th–25th, they sow sorghum in many places

quite unfit for its cultivation, and when the Nile rises after the first check, this sorghum is liable to get drowned.

The statistical information we have about the gauge at Aswan and the Nile's daily rise and fall there, commences from 1870.

The following table shows the gauges of seven typical years:—

TABLE 155.—SEVEN TYPICAL LOW FLOODS.

| Date in August. | Gauge in metres, R.L. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1877. | 1880. | 1881. | 1882. | 1884. | 1886. | 1888. |
| 15 | 90·75 | 92·21 | 91·00 | 90·73 | 91·54 | 92·46 | 91·27 |
| 16 | 91·07 | 92·21 | 91·09 | 90·95 | 91·52 | 92·57 | 91·09 |
| 17 | 91·18 | 92·26 | 91·09 | 91·29 | 91·45 | 92·53 | 91·02 |
| 18 | 91·22 | 92·26 | 91·18 | 91·49 | 91·36 | 92·46 | 91·02 |
| 19 | 91·34 | 92·21 | 91·40 | 91·61 | 91·27 | 92·37 | 91·06 |
| 20 | 91·40 | 92·17 | 91·67 | 91·99 | 91·22 | 92·26 | 91·20 |
| 21 | 91·29 | 92·08 | 91·81 | 92·21 | 91·25 | 92·31 | 91·56 |
| 22 | 91·18 | 91·99 | 91·85 | 92·21 | 91·31 | 92·39 | 91·87 |
| 23 | 91·13 | 91·94 | 91·97 | 92·19 | 91·31 | 92·48 | 92·01 |
| 24 | 91·13 | 91·88 | 92·19 | 92·35 | 91·31 | 92·44 | 92·08 |
| 25 | 91·13 | 91·83 | 92·28 | 92·57 | 91·34 | 92·31 | 92·03 |
| 26 | 91·11 | 91·81 | 92·28 | 92·73 | 91·36 | 92·19 | 91·94 |
| 27 | 91·13 | 91·83 | 92·28 | 92·84 | 91·45 | 92·08 | 91·87 |
| 28 | 91·18 | 92·06 | 92·39 | 93·00 | 91·76 | 92·17 | 91·78 |
| 29 | 91·18 | 92·28 | 92·62 | 92·93 | 92·21 | 92·26 | 91·72 |
| 30 | 91·18 | 92·37 | 92·87 | 92·73 | 92·55 | 92·26 | 91·74 |
| 31 | 91·16 | 92·48 | 92·98 | 92·64 | 92·66 | 92·21 | 91·78 |

In 1877, the worst year of the century, the low Nile would have been declared by rule No. 1.

In 1888 it would not have been declared till 28th August, as the steady flow above 14 cubits or 6·50 gave promise of better things.

In 1880, 1882, and 1886 it would not have been declared, as the rise after the 15th was so good that considerable progress must have been made with the irrigation before 28th August.

In the year 1886, the Nile rose to above 16 cubits or 8 metres in September and removed all difficulties. In 1880 and 1882, however, the Nile was weak all through September, and though statistics are wanting in 1882, the people must have been put to very great expense by having to irrigate by lift all the Nile berms.

There were about 25,000 acres actual drought in 1880 down to Assiut.

In 1884 the low Nile would have been declared by rule 2, and much good would have been done by storage of water in the intermediate basins.

Even with the remodelled system, there is a very large width of the land immediately bordering the Nile which the people habitually irrigate by low lift, unless the Nile has risen above R.L. 93·50 metres. The irrigation of this tract is not maintained by Government, as the people, more especially in Kena and south Girga, have occupied it by villages. They maintain short canals running down the

tract whose beds are on about R.L. 91·50 metre gauge, and which therefore run absolutely dry when the Nile sinks below R.L. 91·50 metres. In this category of privately irrigated Nile berm are included all the real islands, *i.e.* patches of land separated from the main land, when the river has risen above R.L. 90·50 metres.

*N.B.*—It may be noted here that in the Arabic Revenue Department, all land between the two great Nile banks is called 'Gezîra' or island, and is distinguished by the phrase 'Gezîra muttasila' and 'Gezîra munfasila,' *i.e.* the island joined to and the island separated from the main land.

In this category also may be included all the immediate berms of the great canals. For example, in the Shanhurîa first 15 kilometres, the whole of this length is closely cultivated by people who live in hamlets built on the spoil bank, and who cultivate for several hundred metres from the main canal by private watercourses. In this category also may be included all the strips of land bordering the desert where there is not room for a basin system with its canals, and where almost always the people lift on to the desert the water either from the Nile or from a canal parallel to the Nile whose bed, even if maintained by Government, is not lower than a R.L. 91·00-metre gauge.

Now all these most industrious people are much inconvenienced by the non-rising of the Nile, and especially so *if the Nile is feeble* and below R.L. 91·50 metres in the beginning of the season. For it is a well-known fact that the preparation of the land for sowing takes more water to wet it for the plough than in any subsequent watering, and thus the delay in getting in the seed is very marked. So much so, that many do not get their sorghum sown until the first week in September.

*To aid these people, I think the Government should*:—

1. Manufacture and keep in stock Archimedean screws. It is found in the Delta that, up to 80 centimetres lift, these instruments, called in Arabic 'Barîma,' give a much larger duty than any other machine. If an iron Archimedean screw could be invented with its pieces interchangeable, the pieces could be stowed away in magazines and served out in low Niles.

2. The Government should also, after 1st September, issue maize seed to the cultivators who, by reason of the struggle for irrigation, have not been able to sow before 1st September. The maize gives a very good return in sixty days, whereas the sorghum requires 100–110 at least.

The evils resulting from sorghum sown in September are: (1) Diminished yield from cold; (2) Occupation of the land to such a late date as to interfere with the sowing of lentils or barley.

By a little judicious arrangement in these two matters, Government might so much facilitate the irrigation of the lands that next low year it could righteously claim full rent. In 1888, the half of the rent was remitted on these lands in many places."

46. **Basin Irrigation Notes, 1895, 1896.**—During a two years' examination of the whole of Egypt as Director-General of Land Tax Adjustment, Sir William Willcocks made the following notes on basin irrigation as he saw it in 1895 and 1896:—

"The four main elements on which rents are based are the following:—

1. A plentiful supply of red water between 15th August and 10th October. This fixes the quality of the soil.

2. Plentiful subsoil water at a moderate depth below the surface of the ground.

3. The presence of ancient ruins, or of nitrate deposits in the deserts.

4. The timely discharge of the water from the basins.

These elements are not placed in order of importance, nor indeed can there be any such order. In el-Iswid basin of Giza Province, the rise of spring level, owing to the regulation of the Barrage, is being taken advantage of to convert this part of Giza into a perennial tract like Kaliubia or Southern Menufia. No canals are needed. The change is being effected by well irrigation. Farmyard manure is plentiful, and basin irrigation is becoming unnecessary. Here subsoil water is the main factor. In the Beni Smia and Enêbis basins, the red water supply is so plentiful and timely that the rentals of the basins approach that of good perennial land. Again, in the deserts bordering Edfu and Esna, the nitrate deposits are so plentiful, that, with their aid, some of the poorest irrigated land in Egypt is rendered capable of supporting a dense population. Round Abydos as a centre, with numerous ruined cities and good subsoil water, there is a cultivation as intense and a population as dense as in Menufia. Northern Assiut and Northern Giza would produce better crops if the basin water could be more quickly discharged ; while Southern Beni Suef and Northern Minia would be considerably improved if the water were allowed to stand much longer on the basins.

The most contented parts of Upper Egypt are the left bank of the Nile from Luxor to Abutîg, and the right bank from Maala to the northern end of Markas Abnûb. Here was spent the mass of the special drought (Sharâki) loan. Colonel Ross's works, with local and insignificant exceptions, have ensured good and timely irrigation.

*Gêdi, or summer millets*, permit of the basins being double cropped and yet thoroughly irrigated and washed. It might be encouraged wherever red water is obtainable. '*Nabâri*,' *or flood millets*, on the other hand, interfere with basin irrigation, and end in the lands becoming salted both from infiltration and from the deleterious salts contained in the nitrate deposits and in the ancient ruin manures which are very freely applied to the millets. The increase of Nabâri millets does not mean any rise in the rentals of the basins, while the increase of Gêdi does. I have heard Mr Wilson express almost exactly the same opinion as the fellahin on this subject.

South of Luxor irrigation will always be difficult, as the slope of the Nile Valley and the Nile itself are the same, and the canals do not gain on the river, owing to alignment, as they do lower down. The new works have improved the irrigation during low flood years, but they have, on the contrary, deprived the basins of much red water irrigation in years of high flood. Special works will have to be made here for passing high floods into the basins or this land will continue to deteriorate.

*The fellahin classify the basin canals as* '*muddy*,' *or* '*sandy*,' according as the water they carry is rich in slime or not. They naturally prefer the muddy canals, of which the Sohagia is the arch type. Such canals, they say, take off severe curves of the Nile, and have no shoals or shifting islands near their heads. The sandy canals are of the type of the Girgawia (the worst of all) and the Ibrahimia, which take off straight reaches with shifting shoals near their heads. Village headmen have frequently informed me that they would far sooner have their lands in the fourth or fifth basin of the Sohagia than in the first of the Ibrahimia or the

Girgawia, which enjoy a very bad reputation. They propose the removal of their heads, but that is practically out of the question.

The training of the Nile for 7 or 8 kilometres upstream of the heads of canals which are encumbered with shoals might suffice to improve the canals.

It has already been stated that the rents of the lands south of Assiut, where Colonel Ross spent nearly all the drought prevention loan, are steadily rising and will continue to rise. This additional wealth is making itself evident in the construction of wells for the utilisation of the subsoil water. *Subsoil water* will prove a mine of wealth to the country in the future when the manure question has been settled. An important landed proprietor in Girga told me that the works had so improved the deposits on his land that he had begun to cover his property with masonry wells, and in 1895–96 had obtained 8 ardebs of beans per acre in the winter, and 19 ardebs of sorghum per acre in the summer after clover.

*The basins of Northern Assiut, Minia, and Beni Suef* are never liable to drought, as they can always be irrigated with escape water; nothing was consequently done towards their improvement out of the drought loan. Very many of these basins are, however, among the poorest in Egypt. With the exception of Ashmunên at one end and Ahnas at the other, there are practically no ancient ruins for manure, and the deserts supply no nitrates. The amount of red water received in flood must always have been deficient, as the quality of the soil is often very inferior, while the construction of the Ibrahimia Canal in 1874 cut them entirely off their red water supply. The numerous red water feeders constructed by Major Brown out of ordinary funds have begun to give many of them a fresh lease of life in years of high flood, but in years of low flood they receive only five or six days' irrigation with white water discharged from the upper basins. The basins on the west of the Yusufi in Minia which have no red water feeders have a mean rental of 180 piastres * per acre, while the basins on the right bank which have been provided with red water feeders have had their mean rents raised to 235 piastres, or a gain of 55 piastres per acre. If these lands were provided with permanent red water feeders † on the Girga and Southern Assiut scale, the rents would rise to 300 and 325 piastres per acre as they have in Girga, or a further gain of from 65 to 90 piastres per acre. No irrigation work in Egypt to-day would yield a larger profit in proportion to the money spent than the improvement of the basin systems of Northern Assiut, Minia, and Beni Suef."

47. **Basin Canal Discharges, 1892, 1893.**—During the preparation of the reservoir projects, the irrigation officers of Upper Egypt and those of the reservoir survey, took discharges of all the basin canals of Upper Egypt in 1892 (a very high year) and in 1893 (a moderately low one). The results are recorded in the two following tables.

"It will be noted that in 1892, with the Aswan gauge reading R.L. 93·80 metres on the 10th September, the basin canals were discharging 3630 cubic metres per second, or 30 per cent. of the total discharge of 12,100 cubic metres. In 1893, with the Aswan gauge reading R.L. 92·00 metres on the 15th August, the canals were discharging 2040 cubic metres per second, or 27 per cent. of the total discharge of 7600 cubic metres. The Cairo gauge on this latter date was R.L. 18·05

* £1 = 100 piastres. † Since provided.

metres, and the discharge 5550 cubic metres per second. The maximum discharges of the Ibrahimia and Sohagia Canals in 1894 were 740 and 520 cubic metres per second respectively.

TABLE 156.—DISCHARGES OF THE CANALS IN UPPER EGYPT IN 1892.
*Canal Discharges between Aswan and Assiut.* (Cubic metres per second.)

| Name of Canal. | August | | | | September | | |
|---|---|---|---|---|---|---|---|
| | 15. | 20. | 25. | 31. | 5. | 10. | 15. |
| Ramâdi . . . | 55 | 66 | 80 | 76 | 82 | 85 | 89 |
| Um-Ads . . . | 8 | 9 | 12 | 13 | 16 | 18 | 20 |
| Afsûn . . . | 25 | 29 | 37 | 39 | 42 | 43 | 45 |
| Fadilia . . . | 12 | 26 | 44 | 49 | 52 | 55 | 50 |
| Tukh . . . | 10 | 19 | 37 | 42 | 44 | 58 | 60 |
| Rannan . . . | 28 | 36 | 53 | 59 | 62 | 67 | 70 |
| Dumrania . . | 26 | 35 | 56 | 62 | 65 | 70 | 74 |
| Rashwania . . | 35 | 41 | 58 | 61 | 64 | 70 | 73 |
| Kasra . . . | 49 | 62 | 104 | 133 | 138 | 150 | 150 |
| Zarzuria . . . | 24 | 30 | 64 | 76 | 77 | 90 | 90 |
| Girgawia . . . | 54 | 59 | 84 | 95 | 96 | 120 | 120 |
| Sohagia . . . | 380 | 386 | 470 | 485 | 492 | 520 | 500 |
| Tahta . . . | 44 | 45 | 66 | 75 | 77 | 82 | 85 |
| Shatura . . . | 25 | 24 | 39 | 47 | 49 | 45 | 40 |
| Ibrahimia . . | 460 | 440 | 540 | 600 | 640 | 700 | 740 |
| Waladia . . . | 6 | 6 | 14 | 20 | 24 | 24 | 24 |
| Minor canals . . | 10 | 15 | 20 | 30 | 30 | 30 | 20 |
| Total, left bank . | 1250 | 1320 | 1790 | 1908 | 2060 | 2250 | 2270 |
| Kilabia . . . | 6 | 11 | 17 | 20 | 24 | 28 | 32 |
| Maala . . . | 5 | 5 | 18 | 22 | 26 | 30 | 32 |
| Bayadia . . . | 30 | 36 | 62 | 69 | 77 | 85 | 90 |
| Shanhuria . . | 46 | 55 | 98 | 108 | 116 | 120 | 125 |
| Shekhia . . . | 5 | 6 | 10 | 11 | 12 | 12 | 12 |
| Ghilasi . . | 19 | 30 | 58 | 64 | 68 | 70 | 72 |
| Samatha . . . | 12 | 19 | 41 | 48 | 52 | 60 | 60 |
| Tarif . . . | 10 | 15 | 20 | 25 | 25 | 25 | 25 |
| Hawis . . . | 15 | 22 | 38 | 41 | 44 | 51 | 56 |
| Ahaiwia . . . | 10 | 15 | 20 | 25 | 25 | 25 | 25 |
| Isawia . . . | 35 | 35 | 55 | 60 | 63 | 70 | 70 |
| Khazindaria . . | 63 | 62 | 86 | 96 | 98 | 110 | 95 |
| Maana . . . | 35 | 41 | 58 | 67 | 71 | 80 | 85 |
| Sant. . . . | 6 | 7 | 8 | 10 | 10 | 12 | 12 |
| Minor canals . . | 4 | 8 | 12 | 15 | 15 | 15 | 15 |
| Total, right bank . | 300 | 370 | 600 | 680 | 730 | 800 | 810 |
| Total, both banks. | 1550 | 1690 | 2390 | 2660 | 2790 | 3050 | 3080 |

TABLE 156.—DISCHARGES OF THE CANALS IN UPPER EGYPT IN 1892 (*continued*).

*Canal Discharges between Assiut and Cairo.* (Cubic metres per second.)

| Name of Canal. | August | | | | September | | |
|---|---|---|---|---|---|---|---|
| | 15. | 20. | 25. | 31. | 5. | 10. | 15. |
| Beni Husain . . | 13 | 16 | 20 | 30 | 35 | 40 | |
| Abu-Bakra . . | 53 | 38 | 60 | 80 | 85 | 93 | |
| Sultani . . . | 18 | 10 | 20 | 37 | 38 | 48 | |
| Nina . . . | 9 | 5 | 10 | 20 | 20 | 20 | |
| Bahabshin . . | 12 | 8 | 14 | 27 | 28 | 33 | |
| Magnuna . . | 15 | 15 | 22 | 40 | 45 | 45 | |
| Koshêsha . . | 70 | 70 | 70 | 70 | 70 | 70 | |
| Zawia . . . | 11 | 7 | 16 | 27 | 28 | 33 | |
| Girza . . . | 40 | 38 | 70 | 95 | 100 | 100 | |
| Zumr . . . | 13 | 12 | 14 | 19 | 20 | 19 | |
| Minor canals . . | 2 | 2 | 4 | 4 | 4 | 4 | |
| Total, left bank . | 260 | 220 | 320 | 450 | 480 | 500 | |
| Ali Bey . . . | 14 | 13 | 28 | 33 | 20 | 18 | |
| Khassâb . . . | 19 | 14 | 25 | 35 | 40 | 46 | |
| Minor canals . . | 7 | 6 | 12 | 12 | 14 | 14 | |
| Total, right bank . | 40 | 30 | 70 | 80 | 80 | 80 | |
| Total, both banks . | 300 | 250 | 390 | 530 | 560 | 580 | |

*Canal Discharges between Aswan and Cairo.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Left bank . . | 1510 | 1540 | 2110 | 2430 | 2540 | 2750 | |
| Right bank . . | 340 | 400 | 670 | 760 | 810 | 880 | |
| Total . . . | 1850 | 1940 | 2780 | 3190 | 3390 | 3630 | |
| Aswan gauge * . . | 6·7 | 7·4 | 8·3 | 8·3 | 8·6 | 8·8 | 8·7 |
| Assiut gauge . . | 6·1 | 5·9 | 6·8 | 7·2 | 7·4 | 7·7 | 8·1 |
| Cairo gauge . . | 5·8 | 5·5 | 5·8 | 6·7 | 7·0 | 7·2 | 7·7 |

* To find R.L. add 85·00 to Aswan, 45·05 to Assiut, and 12·25 to Cairo.

TABLE 157—DISCHARGES OF THE CANALS IN UPPER EGYPT IN 1893.

*Canal Discharges between Aswan and Assiut.* (Cubic metres per second.)

| Name of Canal. | August | | | | September | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 15. | 20. | 25. | 31. | 5. | 10. | 15. | 20. | 25. | 30. |
| Ramâdi | 50 | 56 | 58 | 56 | 55 | 60 | 64 | 61 | 64 | 61 |
| Um-Ads | 10 | 12 | 12 | 12 | 13 | 14 | 15 | 15 | 15 | 15 |
| Asfûn | 28 | 33 | 34 | 33 | 31 | 33 | 35 | 33 | 34 | 33 |
| Fadilia | 17 | 24 | 26 | 26 | 22 | 24 | 29 | 24 | 22 | 20 |
| Tukh | 19 | 24 | 26 | 27 | 21 | 24 | 24 | 22 | 27 | 26 |
| Rannan | 20 | 26 | 29 | 28 | 25 | 25 | 30 | 27 | 30 | 28 |
| Dumrania | 33 | 39 | 44 | 43 | 39 | 41 | 46 | 43 | 46 | 44 |
| Rashwania | 45 | 52 | 60 | 55 | 50 | 53 | 68 | 60 | 65 | 60 |
| Kasra | 70 | 72 | 82 | 79 | 72 | 76 | 87 | 82 | 87 | 82 |
| Zarzuria | 38 | 44 | 47 | 46 | 45 | 47 | 52 | 46 | 52 | 46 |
| Girgawia | 55 | 55 | 59 | 58 | 56 | 56 | 62 | 57 | 62 | 57 |
| Sohagia | 390 | 380 | 400 | 390 | 350 | 360 | 420 | 390 | 430 | 410 |
| Tahta | 45 | 46 | 47 | 46 | 44 | 45 | 51 | 44 | 52 | 47 |
| Shatura | 20 | 23 | 26 | 25 | 22 | 17 | 28 | 25 | 29 | 28 |
| Ibrahimia | 520 | 520 | 560 | 560 | 540 | 540 | 600 | 580 | 600 | 600 |
| Waladia | 10 | 11 | 12 | 12 | 11 | 11 | 11 | 12 | 12 | 12 |
| Minor canals | 10 | 15 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Total, left bank | 1380 | 1430 | 1550 | 1510 | 1420 | 1440 | 1640 | 1540 | 1650 | 1590 |
| Kilabia | 11 | 13 | 15 | 14 | 14 | 15 | 17 | 16 | 16 | 16 |
| Maala | 11 | 12 | 13 | 12 | 13 | 14 | 16 | 16 | 16 | 16 |
| Bayadia | 36 | 44 | 48 | 46 | 40 | 45 | 52 | 44 | 42 | 30 |
| Shanhuria | 56 | 64 | 69 | 63 | 62 | 64 | 70 | 50 | 40 | 30 |
| Shekhia | 6 | 7 | 9 | 8 | 6 | 6 | 4 | 5 | 6 | 6 |
| Ghilasi | 24 | 32 | 34 | 32 | 29 | 30 | 35 | 31 | 34 | 33 |
| Samatha | 17 | 24 | 27 | 25 | 22 | 24 | 28 | 25 | 27 | 26 |
| Tarif | 12 | 14 | 16 | 15 | 14 | 15 | 17 | 16 | 17 | 16 |
| Hawis | 24 | 27 | 29 | 29 | 27 | 27 | 29 | 27 | 25 | 16 |
| Ahaiwia | 15 | 16 | 16 | 16 | 12 | 12 | 10 | 7 | 4 | 4 |
| Isawia | 30 | 37 | 40 | 37 | 37 | 39 | 40 | 40 | 43 | 40 |
| Khazindaria | 60 | 62 | 67 | 66 | 60 | 60 | 66 | 65 | 55 | 50 |
| Maana | 29 | 30 | 32 | 32 | 29 | 32 | 33 | 34 | 24 | 24 |
| Sant | 6 | 6 | 9 | 8 | 7 | 7 | 7 | 7 | 7 | 7 |
| Minor canals | 4 | 7 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Total, right bank | 340 | 400 | 430 | 410 | 390 | 400 | 430 | 390 | 370 | 320 |
| Total, both banks | 1720 | 1830 | 1980 | 1920 | 1810 | 1840 | 2070 | 1930 | 2020 | 1910 |

TABLE 157.—DISCHARGES OF THE CANALS IN UPPER EGYPT IN 1893 (*continued*).

*Canal Discharges between Assiut and Cairo.* (Cubic metres per second.)

| Name of Canal. | August | | | | September | | | | | | October | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15. | 20. | 25. | 31. | 5. | 10. | 15. | 20. | 25. | 30. | 5. | 10. | 15. | 20. | 25. |
| Beni Husain | 17 | 18 | 19 | 20 | 14 | 12 | 16 | 17 | 17 | 17 | | | | | |
| Abu-Bakra | 63 | 50 | 63 | 64 | 60 | 58 | 68 | 65 | 64 | 64 | | | | | |
| Sultani | 17 | 16 | 17 | 17 | 16 | 15 | 17 | 17 | 17 | 17 | | | | | |
| Nina | 9 | 8 | 9 | 10 | 10 | 9 | 9 | 9 | 9 | 9 | | | | | |
| Bahabshin | 11 | 9 | 11 | 12 | 12 | 10 | 12 | 11 | 13 | 14 | | | | | |
| Magnuna | 21 | 20 | 20 | 20 | 24 | 23 | 28 | 29 | 30 | 30 | | | | | |
| Koshêsha | 70 | 70 | 50 | 30 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| Zawia | 11 | 8 | 13 | 12 | 13 | 12 | 13 | 15 | 16 | 17 | | | | | |
| Girza | 50 | 45 | 50 | 55 | 60 | 60 | 50 | 50 | 40 | 30 | | | | | |
| Zumr | 10 | 10 | 10 | 10 | 6 | 6 | 7 | 12 | 14 | 15 | | | | | |
| Minor canals | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | | | | |
| Total, left bank | 280 | 260 | 260 | 250 | 220 | 210 | 220 | 220 | 220 | 220 | | | | | |
| Ali bey | 16 | 20 | 27 | 28 | 15 | 12 | 15 | 17 | 20 | 20 | | | | | |
| Khassâb | 20 | 20 | 20 | 22 | 19 | 15 | 19 | 15 | 15 | 18 | | | | | |
| Minor canals | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | | | | | |
| Total, right bank | 40 | 50 | 50 | 60 | 40 | 30 | 40 | 40 | 40 | 50 | | | | | |
| Total, both banks | 320 | 310 | 310 | 310 | 260 | 240 | 260 | 260 | 260 | 270 | | | | | |

*Canal Discharges between Aswan and Cairo.*

| | August | | | | September | | | | | | October | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15. | 20. | 25. | 31. | 5. | 10. | 15. | 20. | 25. | 30. | 5. | 10. | 15. | 20. | 25. |
| Left bank | 1660 | 1690 | 1810 | 1760 | 1640 | 1650 | 1960 | 1760 | 1870 | 1810 | | | | | |
| Right bank | 380 | 450 | 480 | 470 | 430 | 430 | 470 | 430 | 410 | 370 | | | | | |
| Total | 2040 | 2140 | 2290 | 2230 | 2070 | 2080 | 2330 | 2190 | 2280 | 2180 | | | | | |
| Aswan gauge * | 7·0 | 7·3 | 7·4 | 7·3 | 7·2 | 7·5 | 7·6 | 7·4 | 7·1 | 7·3 | 7·1 | 7·3 | 6·9 | 6·3 | 6·0 |
| Assiut gauge | 6·2 | 6·2 | 6·4 | 6·3 | 6·2 | 6·3 | 6·5 | 6·5 | 6·6 | 6·6 | 6·4 | 6·5 | 6·7 | 6·7 | |
| Cairo gauge | 5·8 | 5·6 | 5·9 | 6·0 | 6·0 | 5·8 | 6·0 | 6·0 | 6·1 | 6·3 | 6·2 | 6·1 | 6·4 | 6·5 | 2·7 |

* To find R.L. add 85·00 to Aswan, 45·05 to Assiut, and 12·25 to Cairo.

By plotting these discharges and drawing curves, and applying them to the minimum, mean, and maximum years, it will be found that the 1,435,000 acres of basins receive in a minimum year 1400 cubic metres per second for forty-five days, in a mean year 2100, and in a maximum year 3200.

This means that in a minimum year 1 cubic metre per second irrigates 1030 acres; in a mean year 690 acres; in a maximum year 450 acres; or in other

words, in a minimum year 1 acre receives in twenty-four hours 83 cubic metres; in a mean year 125 cubic metres; in a maximum year 190 cubic metres.

All the basins do not, however, receive equal amounts. Taking a mean year as a basis, the following table gives the quantities received by the different systems of basins.

TABLE 158.—WATER SUPPLIED TO BASINS IN A MEAN YEAR.

| Name of Basin System. | Area in acres. | Discharge in cubic metres per second. | Cubic metres per acre per 24 hours. | Remarks. |
|---|---|---|---|---|
| Aswan (minor) . | 5,000 | 5 | 80 | For 45 days in a mean year. |
| Ramâdi-Farshût | 187,000 | 260 | 120 | " " " |
| Kena, right . | 114,000 | 200 | 150 | " " " |
| Girga, right . | 48,000 | 80 | 150 | " " " |
| Kasra-Girgawia . | 112,000 | 220 | 170 | " " " |
| Sohagia-Delgawi | 324,000 | 640 | 170 | " " " |
| Waladia . . | 30,000 | 25 | 70 | " " " |
| Assiut, right . | 73,000 | 110 | 135 | " " " |
| Yusufi . . | 421,000 | 460 | 90 | " " " |
| Minia and Beni Suef, right . | 16,000 | 10 | 50 | " " " |
| Giza, left . . | 80,000 | 70 | 75 | 60 to 70 days in a mean year. |
| Giza, right. . | 25,000 | 20 | 70 | " " " |
| Total. . | 1,435,000 | 2,100 | 125 | Mean year." |

48. **The Basins of Upper Egypt by Systems, with their Areas and Summer Crops in 1897.**—During the Land Tax adjustment operations of 1897 in Upper Egypt a careful record was made of the summer crops in the basins and other interesting agricultural information. It is recorded here for future reference.

[TABLE

TABLE 159.—LIST OF BASINS BY SYSTEMS IN 1897.

| System of Basins. | Area in Acres. | Renting Value per Acre. | Area of Flood and Summer Crops. | | | |
|---|---|---|---|---|---|---|
| | | | Sugar-Cane. | Cotton. | Summer Sorghum. | Flood Sorghum. |
| *Left Bank of the Nile.* | | £ | | | | |
| Banban . . . | 1,700 | 1·80 | ... | ... | 220 | 80 |
| Ramâdi . . . | 53,900 | 2·50 | 2020 | ... | 1,600 | 14,800 |
| Asfûn . . . | 24,000 | 2·75 | 3500 | ... | 5,250 | 4,060 |
| Fadilia . . . | 22,700 | 2·70 | 250 | ... | 1,390 | 910 |
| Sahil Farshût . . | 72,800 | 3·25 | 2350 | ... | 5,000 | 3,560 |
| Kasra-Girgawia . . | 111,700 | 3·50 | 2960 | ... | 14,670 | 5,240 |
| Sohagia-Delgawi . | 324,600 | 3·75 | 1630 | ... | 31,010 | 9,000 |
| Waladia . . . | 29,900 | 3·25 | 360 | ... | 1,000 | 2,310 |
| Right Yusufi . . | 303,200 | 3·30 | 1690 | 2730 | 11,300 | 4,500 |
| Left Yusufi . . | 105,000 | 2·00 | 10 | 4450 | 2,800 | 6,000 |
| Rikka . . . | 12,400 | 3·20 | 60 | ... | 1,100 | ... |
| Left Giza . . . | 80,200 | 3·50 | 4210 | 2730 | 10,870 | 1,590 |
| *Right Bank of the Nile.* | | | | | | |
| Khattara Ridisia . | 5,600 | 1·90 | ... | ... | 350 | 2,410 |
| Kilabia . . . | 12,400 | 2·50 | ... | ... | 1,220 | 2,790 |
| Bayadia . . . | 19,800 | 3·0 | 380 | ... | 1,850 | 1,150 |
| Shanhuria . . . | 46,000 | 3·0 | 110 | ... | 4,720 | 1,830 |
| Ghilasi . . . | 63,400 | 3·25 | 1580 | ... | 3,120 | 2,250 |
| Khiâm . . . | 24,600 | 3·00 | 190 | ... | 500 | 3,500 |
| Akhmîm . . . | 23,000 | 3·40 | 80 | ... | 1,150 | 3,850 |
| Khazindaria . . | 34,000 | 3·40 | 140 | 60 | 4,700 | 2,270 |
| Abnûb . . . | 38,800 | 3·50 | 10 | ... | 5,430 | 2,200 |
| Right Minia . . | 14,600 | 3·30 | 4000 | 350 | 550 | 500 |
| Right Beni Suef . . | 1,200 | 2·60 | 30 | 20 | 30 | 200 |
| Right Giza . . | 25,400 | 3·50 | 260 | 200 | 1,880 | 6,610 |

TABLE 160.—BASINS BY PROVINCES IN 1897.

| Province. | Total Area in Basins. | Cotton. | Sugar-Cane. | Summer Sorghum. | Flood Sorghum. | Remarks. |
|---|---|---|---|---|---|---|
| | acres | acres | acres | acres | acres | |
| Aswan . | 19,800 | ... | ... | 1,000 | 7,000 | During years of low flood the areas under flood sorghum are very considerably increased. |
| Kena . | 286,600 | ... | 10,000 | 23,000 | 27,000 | |
| Sohag . | 275,500 | ... | 3,500 | 29,000 | 20,000 | |
| Assiut . | 363,800 | ... | 3,500 | 35,000 | 11,000 | |
| Minia . | 208,000 | 2,000 | 4,000 | 4,000 | 8,000 | |
| Beni Suef | 175,700 | 6,000 | ... | 8,000 | 1,000 | |
| Giza . | 105,600 | 3,000 | 4,000 | 13,000 | 8,000 | |
| Total . | 1,435,000 | 11,000 | 25,000 | 113,000 | 82,000 | |

In addition to the above are the areas of summer and flood crops sown on the Nile berms and islands. The area of flood sorghum which is sown depends entirely

on the flood. In an ordinary flood the following areas may be considered fairly representative:—

TABLE 161.—SORGHUM ON NILE BERMS.

| Province. | Area of Nile Berms and Islands. | Flood Sorghum and Maize. |
|---|---|---|
| | acres | acres |
| Aswan | 53,700 | 20,000 |
| Kena | 56,300 | 50,000 |
| Sohag | 49,500 | 20,000 |
| Assiut | 24,900 | 8,000 |
| Minia | 33,000 | 14,000 |
| Beni Suef | 8,900 | 3,000 |
| Giza | 70,500 | 35,000 |
| Total | 296,800 | 150,000 |

49. **Basin Irrigation Details in 1897.**—The systems of basins have been greatly modified since 1897, but we consider it useful to record for future reference how matters stood in 1897 at the time of the Land Tax Adjustment Inquiry. The two following tables give the date of filling and emptying of the basins from 1884 to 1897. The high floods of 1887, 1892, and 1894 are included, as is also the low flood of 1888.

TABLE 162.—DATES OF OPENING OF BASIN CANALS.

| Year. | Kena Province. | Girga Province. | Sohagia Head. | Delgawi Feeder. | Minia Province. | Beni Suef Province. | Giza Province, Left. | Khassâb Canal. | Closing Rayah Behera Head. |
|---|---|---|---|---|---|---|---|---|---|
| | Aug. | Aug. | Aug. | Aug. | Aug. | Aug. | Aug. | Aug. | |
| 1884 | 10 | 10 | 10 | ... | 17 | ... | 19–20 | 11 | Aug. 15 |
| 1885 | 10 | 6–10 | 9 | 8 | 15 | ... | 11–13 | 11 | not closed |
| 1886 | 11–13 | 11–15 | 15 | 19 | 15 | ... | 12–17 | 9 | August |
| 1887 | 10 | 9–13 | 13 | 10 | 15 | ... | 13–14 | 14 | Aug. 1 |
| 1888 | 13–15 | 13–16 | 14 | 14 | 12 | 12–15 | 14–17 | 14 | Sept. 1 |
| 1889 | 6–10 | 12 | 10 | 10 | 15 | 10 | 5–14 | 14 | Sept. 4 |
| 1890 | 15 | 12–15 | 12 | 11 | 14 | 12 | 14 | 15 | Aug. 24 |
| 1891 | 15 | 10–12 | 10 | 15 | 15 | 11 | 13–16 | 16 | Aug. 19 |
| 1892 | 11–15 | 12–15 | 15 | 17 | 15 | 11–17 | 6–8 | 10 | Aug. 17 |
| 1893 | 13 | 15 | 15 | 18 | 16 | 13 | 6–15 | 5 | Aug. 26 |
| 1894 | 15 | 11–15 | 17 | 15 | 15 | 10 | 5–15 | 4 | Aug. 26 |
| 1895 | 15 | 7–15 | 15 | 15 | 15 | 15 | 4–15 | 1 | Aug. 21 |
| 1896 | 10 | 8–13 | 10 | 10 | 10 | 10 | 8–10 | 10 | Sept. 13 |
| 1897 | 10 | 8–10 | 12 | 10 | 10 | 10 | 10–12 | 12 | not closed |

*N.B.*—The date fixed by Khedivial decree for the opening of the basin canals is 10th August; but when summer sorghum crops exist in the basins, Inspectors of Irrigation have the power to delay the opening to 15th August, and in exceptional cases till the crop has been harvested.

TABLE 163.—DATES OF GENERAL DISCHARGE OF BASINS.

| Year. | Kena Province. | Kena to Girga Province. | Sohagia Canal closed. | Abutig Escape opened. | Delgawi Escape opened. | Tahana-shawi opened. | Salakusi opened. | Koshêsha opened. | Attwah opened. | Komi opened. | Rayah Behera opened. | Niklai opened. | Um Dinar opened. | Dêr el tin opened. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Oct. | Oct. | Oct. | Oct. | Oct. | Oct. | | | | | | |
| 1884 | Oct. 10 | Oct. 30 | 27 | 19 | 15 | 19 | 22 | 22 | ... | Oct. 13 | | | | |
| 1885 | Sept. 26 | ,, 1 | 1 | ... | ... | 18 | 22 | 11 | ... | ,, 15 | | | | |
| 1886 | Oct. 5 | ,, 5 | 4 | 8 | 13 | 11 | 17 | left open | ... | ,, 19 | ... | Oct. 28 | not opened | |
| 1887 | ,, 2 | ,, 2 | 4 | 6 | 5 | 16 | 21 | 7 | ... | ,, 14 | Aug. 15 | ,, 2 | Sept. 28 | |
| 1888 | Sept. 27 | ,, 10 | 28 | 28 | 10 | 15 | 19 | 29 | ... | Sept. 28 | Oct. 12 | Aug. 27 | Oct. 12 | |
| 1889 | ,, 28 | ,, 3 | 6 | 12 | 12 | 17 | 23 | 25 | ... | Oct. 8 | ,, 29 | Oct. 29 | not opened | |
| 1890 | Oct. 1 | Nov. 1 | 1 | 7 | 25 | 14 | 18 | 16 | ... | ,, 28 | Nov. 12 | Nov. 20 | Nov. 5 | |
| 1891 | ,, 5 | .. | 10 | 15 | 11 | 13 | 17 | 17 | Oct. 20 | ,, 3 | ,, 3 | ,, 3 | ,, 3 | Nov. 5 |
| 1892 | ,, 6 | Sept. 27 | 15 | 16 | 15 | 17 | 22 | 25 | Sept. 29 | ,, 20 | ,, 13 | ,, 14 | Oct. 11 | Oct. 17 |
| 1893 | ,, 5 | Oct. 20 | 25 | 15 | 17 | 17 | 19 | 23 | Oct. 30 | Sept. 19 | ,, 5 | ,, 6 | Nov. 10 | Nov. 5 |
| 1894 | ,, 5 | Sept. 22 | 24 | 8 | 16 | 18 | 22 | 23 | ,, 26 | Oct. 26 | ,, 9 | Oct. 29 | Oct. 29 | ,, 5 |
| 1895 | ,, 4 | Oct. 4 | 12 | 10 | 12 | 13 | 16 | 19 | ,, 27 | ,, 1 | Oct. 28 | ,, 13 | ,, 20 | ,, 5 |
| 1896 | ,, 1 | ,, 1 | 11 | 9 | 16 | 17 | 20 | 23 | ,, 25 | ,, 3 | ,, 10 | ,, 18 | ,, 2 | ,, 5 |
| 1897 | ,, 1 | ,, 15 From 1892 Abu Shusha Escape | 19 | 16 | 17 | 12 | 15 | 20 | ,, 12 | Nov. 20 | open through flood | Nov. 3 | Nov. 3 | not opened |

In 1897 the summer and flood irrigation in the basins was performed or supplemented by 5400 water-wheels on the Nile and on canals; 74 stationary engines with a joint h.p. of 3500; 81 portable engines with a joint h.p. of 890; 17,340 water-wheels on wells in the basins; 17,700 shadufs on the Nile, south of Assiut; and 5900 shadufs in the basins and on canals south of Assiut.

The number of masonry regulators was 490, of escapes 102, of syphons 40. The kilometrage of basin canals was 3548, of basin drains 313, of basin banks 2281; and of Nile banks 1409.

The earthwork maintenance cost £150,000 per annum, the masonry works maintenance £20,000, the flood protection £2000. The total cost of maintenance was £172,000. As the number of acres under flood irrigation was 1,732,000, the cost of maintenance per acre was £·10 per annum.

The prime cost of the works might be put down at approximately £5,200,000, or £3 per acre.

50. **Notes on the Basin Tracts during the Land Tax Adjustment Operations of 1896.**—The following notes were made during the Land Tax adjustment operations and published in the second edition of this book in 1897:—

"*Province of Aswan*, 1897.

Owing to the large proportion of the land lying within reach of the river, the land is irrigated to a great extent throughout the year. The greater part of the dense population spend their lives lifting water from the Nile on to their fields. Cattle are costly to keep, and consequently everything is done by manual labour. The resident population south of Aswan receive considerable aid from their relatives in Cairo, Alexandria, and the cities of the Delta, where they have monopolised the occupation of cooks and house servants of all classes.

The hills provide nitrates in plenty, and the lands are generally well cultivated, though the yield is poor, as the water has to be lifted to so great a height. Between Halfa and Aswan there are 800 acres of land at Deberra which are irrigated as basins in an ordinary flood, and a small tract south of Korosko which is irrigated flush in a high flood. With these exceptions, the area south of Aswan is irrigated lift throughout the year. The lift varies from 8 to 10 metres in summer, and 1 to 3 metres in flood. Between Aswan and Kelh are a few insignificant basins on the right bank, and one or two good basins on the Ramâdi Canal near Edfu. The greater part of the land is irrigated lift except in good floods.

The principal crops are sorghum, pulse (âds), barley, vetches (gilbân), beans (ashrangêk), lettuce, and castor oil. Beans and wheat are grown on the rich basin lands, while the foreshores are covered with melons and cucumbers. The date-palm is being extensively cultivated, especially at Ibrim and the surrounding villages.

The most valuable lands in this province and in Kena are the recently formed and low-lying berms of the Nile, while the least valuable are the ancient and high-lying berms which have been heavily manured with nitrates for centuries and never washed by the Nile flood.

*Province of Kena*, 1897.

The hills south of Gebelain provide nitrate in plenty, and north of it in insignificant quantities. There are also a few ancient mounds, such as Mataana,

Edfu, and Dendera, which provide valuable manures. Wherever spring water is abundant, as it is in the neighbourhood of Basilia, Esna, Luxor, and Farshût, and generally along the edges of the desert, there are extensive areas of summer sorghum and sugar-cane, and the winter crops are both manured and irrigated. The area under flood sorghum is also very extensive in this province. The smaller the basin and the shallower the water in flood, the more extensive is the sorghum crop as a rule. Double cropping is becoming a necessity in these southern provinces, owing to the great increase of population and the presence of so many mouths to feed.

The province of Kena in the neighbourhood of Naga Hammadi has numerous mills and molasses factories scattered among the villages belonging to the fellahin themselves. The sugar-cane is grown in the basin enclosures, and irrigated from wells in the fields worked by Persian wheels.

The principal crops are sorghum, wheat, beans, pulse (âds), vetches (gilbân) south of Kena, and clover north of Kena, barley, sugar-cane, melons, and cucumbers.

The basins are generally well irrigated, and supplied with abundance of water in the northern parts of the province. The southern basins are well irrigated, but not very plentifully, as the slope of the country does not permit it. The Samhûd basin in the extreme north of the province is one of the best irrigated and richest basins in Egypt, while the subsoil water is plentiful.

*Province of Sohag*, 1897.

The large area under basin irrigation on the left or main bank of the Nile as compared to the other kinds of irrigation is a new feature as we descend the Nile. Sohag, indeed, with Southern Assiut, is the centre of basin irrigation in Egypt. Here we see basin irrigation at its best. The land is rich, the crops luxuriant, the people well off and independent, and the subsoil water well utilised. We nowhere again see such general wealth and prosperity until we reach the deltaic province of Menufia. In the centre of one of the richest tracts are the ruins of Abydos, and near by the reputed site of This or Thinis, the first capital of Egypt. And indeed an agricultural community, whose lands are never liable to drought, whose flood waters no engineer can cut off, and whose plentiful subsoil water at a convenient level is their own property with which no Government official or powerful neighbour can interfere, enjoys a freedom and independence which is very rare in Egypt.

This province is the most rainless in Egypt, as it gets its rain neither from the north in winter, nor from the south in autumn. The hills provide no nitrates to speak of, but the cattle are very numerous, and in the south there are many ancient ruins which supply manure. The Nile deposit in the basins is generally very good. Here Colonel Ross spent great part of the £800,000 loan, and improved every basin he touched.

The subsoil springs are generally plentiful, and wells numerous.

A pumping station and sugar factory have recently been erected near Baliana by the Egyptian Sugar and Land Company. The indicated horse-power of the engines for pumping is 400; the discharge per minute is 100 cubic metres; the area capable of irrigation is 4000 acres; and the capacity of sugar out-turn in tons is 7000.

The principal crops are wheat, beans, clover, millets, barley, onions, and sugar-cane.

There are butter factories at Menshia and Tahta, and an ice factory at Tahta.

*Province of Assiut*, 1897.

The basins on the Sohagia Canal from Assiut to Delga have been long deprived of their full share of water from that magnificent canal, but they are being now re-supplied with water from the same source. A syphon is badly needed under the Ibrahimia Canal at its head to connect the basins on its right bank with the Sohagia, from which they were cut off when the Ibrahimia Canal was constructed. The basins north of Assiut are generally poor; but if liberally supplied with water, they ought to regain their ancient fertility. Manfalut, the centre of this tract, was once one of the most prosperous agricultural towns in Egypt, and the centre of sugar-cane cultivation. The basins on the right bank of the Nile are well irrigated, and received considerable attention from Colonel Ross. On the left bank of the Nile the Abutig and Delgawi escapes were built out of the loan for drought prevention, but the drought prevention works may be said to have ceased at the town of Assiut. The whole basin system of irrigation from Assiut to Cairo needs to be thoroughly taken up, and a special grant for this purpose would repay itself in a few years.

The Ibrahimia Canal has its head in this province. It traverses the northern half of the province with its water surface in soil through the winter and summer. North of Deirut it is at a very convenient level for lift irrigation, aided by the Deirutia and Sahilia Canals. This tract has the further advantage of having situated in its centre the extensive mounds of Ashmunên, which supply unlimited manure. The lands are not generally over-irrigated, and some of the best of the Daira property is in this province. The only lands which are decidedly salted and deteriorating are those north of Ashmunên, where high-level canals traverse a very sandy clay soil and have succeeded in saturating and partially ruining it.

The principal crops are wheat, beans, clover, sorghum, sugar-cane, cotton, and barley.

*Province of Minia*, 1897.

The basins on the right bank of the Yusufi Canal are indifferently irrigated, and need far more red water than they receive. To be brought up to first-class level and rendered fit for the introduction of perennial irrigation they should have their red water supply doubled. No project in Egypt would pay better than the remodelling on Colonel Ross's lines of the basin irrigation of these lands coupled with the basin irrigation on the miserably poor lands on the left of the Yusufi Canal. A regulator on the Yusufi Canal opposite Minia, and another at Behnessa, with a new feeder as large as the present Yusufi itself, from the Nile north of Minia would double and treble the value of the land, and in the course of twenty or thirty years render it capable of being perennially irrigated without subjecting it to the deterioration which the inferior Ibrahimia tracts have undergone. At the same time, the flying sand-hills on the west of this province, especially near Balansura, should be planted with grasses and tamarisks. It is generally accepted by all that the basin irrigation west of the Yusufi Canal, inferior and poor as it is, has been the cause of saving the left bank of the Nile from inundation by sand. If these lands could be covered by a great depth of red muddy water for some forty or fifty days every year, instead of as at present with clear white water for some four or five days, the sand which now invades the Yusufi Canal at Balansura would be stopped. This sand at present pours into the Yusufi Canal under the action of the north-west winds, and is

swept in flood on the whole of the lands of the Minia Province irrigated by this canal, doing great harm wherever it goes. By plentiful basin irrigation and intelligently placed plantations all this evil might be stopped. The local people say that this moving sand was not nearly so active and virulent in the past, but that ever since Mohamed Ali settled the refugee Algerian Arabs along the western deserts, their camels and goats have eaten down the desert plants and shrubs, and the sand has begun to live.

The principal crops are sugar-cane, cotton, clover, sorghum, wheat, beans, barley, and onions. The onions are principally grown on the lands annually covered by the Nile in flood.

*Province of Beni Suef*, 1897.

In this province, for the first time, we see a considerable area of perennially irrigated lands in the hands of resident proprietors, and as this land is moreover near the Nile and of good quality in itself, the wealth and well-being of the population are very marked. No town in Egypt has made greater progress during the last fifteen years than the town of Beni Suef. The perennially irrigated land occupies a narrow strip up to Beni Suef and then spreads out over the rich land to the north-west of the town.

The basins of this province, with the exception of the northern halves of Koshêsha and Rikka, are very poorly irrigated. The same remarks apply to them as to the basins of Minia Province. If we compare the Sohagia system with the Yusufi system, we find that the former receives 170 cubic metres per acre per day, and the latter 90. But that is not all. Not only has the Yusufi system a quite insufficient supply, but what there is cannot be utilised owing to the want of regulators, and nearly the whole of it finds its way into the northern half of the Koshêsha basin and irrigates a tract which could be better irrigated direct from the Nile through the escape. It may be stated, without exaggeration, that the whole of the Yusufi Canal supply which enters Beni Suef Province before the time of final discharge is wasted. A great part of the basins in an ordinary year receives only four or five days' irrigation with white water, instead of forty-five days with rich red water.

If the basin system of this province were thoroughly improved on Colonel Ross's lines, the lands in twenty or thirty years would be sufficiently improved to be profitably put under perennial irrigation.

The perennially irrigated tracts north-west of Beni Suef are in great part the property of resident Egyptians, and have, moreover, been gradually changed from basin to perennial irrigation at a rate of 1000 or 1500 acres per annum, so that the proprietors have been able not only to spend all their money on the spot, but also to provide themselves with the stock necessary to work such land properly. The land also is suitable for perennial irrigation and is favourably situated. The presence of large numbers of cattle which compose the stock of the fellahin permits of extensive clover cultivation in winter. Clover again improves land; it permits of land being washed where drains are in existence, eats down salts if they are present in small quantities, and enriches the soil with nitrates. All these facts have combined to make Beni Suef the centre of one of the most successful examples of the benefits to be reaped from perennial cultivation. The deterioration so marked in the northern half of Minia is nowhere to be seen. A careful

examination of the two tracts will convince anybody of the immense benefits to be reaped from perennial irrigation gradually extended and applied to suitable lands, and the losses to be expected from the same irrigation spread broadcast and applied to unsuitable lands.

The principal crops are cotton, wheat, clover, sorghum, beans, barley, sugar-cane, and onions.

*Province of Giza*, 1897.

The principal crops are sorghum, wheat, cotton, sugar-cane, clover, melons, onions, barley, and beans. All round the site of ancient Memphis are very extensive date plantations.

The enclosed area in this province, which for all practical purposes is the same as perennially irrigated land, is exceptionally high, owing to the inferiority of the basin canals, the proximity of Cairo and the excellent subsoil water, especially since the Barrage was repaired and the water-level raised. The spring level, which was originally 4 to 6 metres below the surface, is now from 2 to 4 metres and very convenient for irrigation. The ancient mounds of Cairo provide manures in plenty, and the heavy demands for fodder and milk result in extensive areas being planted with clover. Melons and vegetables of all kinds are extensively sown.

At Ayat is an important pumping station with extensive sugar-cane plantations. The Ayat engine has a horse-power of 400, the discharge is 100 cubic metres per minute, the area capable of irrigation is 4000 acres. At Hawamdia is a sugar factory capable of making 8000 tons of sugar, the out-turn in 1896–97 was 6000 tons, and in 1897–98 was 2500 tons. The sugar factory is attached to the sugar refinery of Egypt. The whole is the property of the Société des Sucreries de la Haute Egypte.

The eastern basin canal is inefficient, and the irrigation of great part of the basins is indifferent. Whenever water is available in summer the lands to the east of the Nile should be given perennial irrigation from a pumping station placed at the head of the Khassâb Canal. Basin irrigation on this narrow strip could not be improved. For the tracts on the west of the Nile the Ibrahimia Canal might be gradually extended to the Barrages and the high lands near the Nile provided with perennial irrigation. As all this land is sandy, the canal should be everywhere in soil and the irrigation 'lift' in winter and summer."

## CHAPTER V.

# *BASIN IRRIGATION* (2).

51. Lists of Basins in 1911.—52. Areas of Land perennially irrigated in the Basin Tracts.—53. Extent and Cost of Works to ensure Basin Irrigation.—54. Improvements during the last Fifteen Years.—55. List of Basin Canals.—56. Date of Filling and Emptying Basins.—57. Notes on the Fifth Circle of Irrigation.—58. Notes on the Girga Circle of Irrigation.—59. Notes on the Assiut Barrage Circle of Irrigation.—60. Notes on the Fourth Circle of Irrigation.—61. Selection from the Irrigation Report for 1894.—62. Selection from the Irrigation Report for 1899.—63. Selection from the Irrigation Report for 1907.—64. Selection from the Irrigation Report for 1908.

51. **List of Basins in 1911.**—The previous chapter has given all the information necessary to understand the system of basin irrigation. It remains to give the details of the system as it exists actually to-day. Since the Aswan reservoir was completed, 405,000 acres of basin land have been converted to perennial irrigation, and irrigated by the water stored in the reservoir. There remains under basin cultivation to-day an area of 995,842 acres. The land on the Nile berms and islands near the basin tracts covers 290,793 acres, so that the total area of land classed as basin land is 1,286,635 acres.

The following table gives details of the basins by systems :—

TABLE 164.—LIST OF BASINS BY SYSTEMS IN UPPER EGYPT.

| Name of System of Basins. | No. of Basins. | R.L. of Full Supply, First Basin. | R.L. of Full Supply, Last Basin. | Acres. | Bank of the Nile. | Province. | Circle of Irrigation. |
|---|---|---|---|---|---|---|---|
| Banban . . . | 1 | 90·25 | 90·25 | 1,640 | Left | Aswan | Fifth |
| Ramâdi . . . | 17 | 86·25 | 80·70 | 38,440 | ,, | Aswan and Kena | ,, |
| Asfûn . . . | 9 | 79·85 | 77·10 | 21,180 | ,, | Kena | ,, |
| Fadilia . . . | 12 | 76·70 | 74·00 | 17,770 | ,, | ,, | ,, |
| Tukh . . . | 9 | 74·10 | 69·40 | 20,200 | ,, | ,, | ,, |
| Farshût . . . | 14 | 67·60 | 65·80 | 45,980 | ,, | ,, | ,, |
| | 62 | Total, left | | 145,210 | ,, | | |

TABLE 164.—*continued.*

| Name of System of Basins. | No. of Basins. | R.L. of Full Supply, First Basin. | R.L. of Full Supply, Last Basin. | Acres. | Bank of the Nile. | Province. | Circle of Irrigation. |
|---|---|---|---|---|---|---|---|
| Khattara . . . | 1 | 92·15 | 92·15 | 370 | Right | Aswan | Fifth |
| Darau . . . | 1 | 90·25 | 90·25 | 1,200 | " | " | " |
| Aklit . . . | 1 | 88·55 | 88·55 | 390 | " | " | " |
| Silwa . . . | 1 | 87·20 | 87·20 | 400 | " | " | " |
| Radasia . . . | 1 | 85·60 | 85·60 | 2,850 | " | " | " |
| Kilabia . . . | 26 | 81·60 | 76·80 | 30,540 | " | Kena | " |
| Bayadia . . . | 5 | 76·40 | 75·30 | 11,750 | " | " | " |
| Shanuria . . . | 10 | 75·10 | 72·20 | 44,480 | " | " | " |
| Ghilâsi . . . | 11 | 71·80 | 68·60 | 43,710 | " | " | " |
| | 57 | Total, right | | 135,690 | " | | |
| Kasra . . . | 35 | 66·10 | 62·50 | 106,355 | Left | Girga | Girga |
| Sohagia . . . | 39 | 61·30 | 55·00 | 197,591 | " | Girga and Assiut | " |
| | 74 | Total, left | | 303,946 | " | | |
| Khyâm . . . | 6 | 67·15 | 65·20 | 25,163 | Right | Girga | " |
| Akhmîm . . . | 8 | 62·20 | 59·60 | 19,210 | " | " | " |
| Khazindaria . . | 15 | 58·20 | 54·40 | 32,000 | " | Girga and Assiut | " |
| | 29 | Total, right | | 76,373 | " | | |
| Assiut . . . | 11 | 52·50 | 43·00 | 123,939 | Left | Assiut | Assiut |
| Walidia . . . | 14 | 52·20 | 46·65 | 24,697 | " | " | " |
| | 25 | Total, left | | 148,636 | " | | |
| Abnûb . . . | 13 | 54·40 | 49·80 | 48,370 | Right | " | " |
| *West Yusufi*— | | | | | | | |
| Nezlet Abîd . . | 5 | 40·10 | 36·25 | 35,464 | Left | Minia and Beni Suef | Fourth |
| Segûla . . . | 5 | 34·30 | 31·50 | 29,600 | " | Beni Suef | " |
| Mazûra . . . | 4 | 30·40 | 28·70 | 12,200 | " | " | " |
| Koshêsha . . | 2 | 26·75 | 26·10 | 8,855 | " | " | " |
| Rikka-Tahma . | 3 | 25·60 | 23·45 | 10,114 | " | Beni Suef and Giza | " |
| | 19 | Total, left | | 96,233 | " | | |
| Dahshur-Iswid . | 6 | 23·00 | 16·75 | 41,383 | ... | Giza | Barrage |
| Total . . | 285 | | | 995,842 | | | |

The average basin to-day has an area of 3500 acres. It was 5000 to 7000 acres twenty years ago.

The following table gives the total land under cultivation in the basin tracts:—

TABLE 165.—AREAS OF LAND IN ACRES IN THE BASIN TRACTS.

| Circle of Irrigation. | Left Bank of the Nile. | | | Right Bank of the Nile. | | | Total. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Basins. | Nile Berms, etc. | Total. | Basins. | Nile Berms. | Total. | Basins. | Nile Berms. | Total. |
| Fifth . | 145,210 | 76,200 | 221,410 | 135,690 | 83,200 | 218,890 | 280,900 | 159,400 | 440,300 |
| Girga . | 303,950 | 26,940 | 330,890 | 76,370 | 27,990 | 104,360 | 380,320 | 54,930 | 435,250 |
| Assiut . | 148,636 | 16,500 | 165,136 | 48,370 | 11,000 | 59,370 | 197,006 | 27,500 | 224,506 |
| Fourth | 96,233 | 20,346 | 116,579 | ... | 18,000 | 18,000 | 96,233 | 38,346 | 134,579 |
| Barrage | 41,383 | 0 | 41,383 | ... | 10,617 | 10,617 | 41,383 | 10,617 | 52,000 |
| Total . | 735,412 | 139,986 | 875,398 | 260,430 | 150,807 | 411,237 | 995,842 | 290,793 | 1,286,635 |

52. **Areas of Land perennially irrigated in the Basin Tracts.**—Large sections of the basin areas have been enclosed by subsidiary dykes and cultivated with sugar-cane and cotton or with millets. Such lands are irrigated by pumps on the Nile or on wells in the basins themselves. Deep bores taken through the compact Nile deposits give a plentiful supply of water which is pumped by companies and sold to the fellahin. In some cases land-owners possess such installations, but the fellahin generally pump up their water by means of sakias worked by oxen or by shadufs worked by men.

The following table gives the number of installations:—

TABLE 166.—WATER-LIFTING ENGINES AND SAKIAS IN THE BASIN TRACTS.

| Circle of Irrigation. | Fixed and Portable Steam and Oil Engines. | | | | | | Sakias. | | |
|---|---|---|---|---|---|---|---|---|---|
| | On the Nile. | | On Canals. | | On Wells in the Fields. | | On the Nile. | On Canals. | On Wells in the Fields. |
| | No. | H.P. | No. | H.P. | No. | I.H.P. | No. | No. | No. |
| Fifth . | 57 | 3393 | 1 | 16 | 70 | 3,000 | 3701 | 491 | 11,289 |
| Girga . | 19 | 480 | ... | ... | 396 | 6,000 | 14 | 47 | 16,476 |
| Assiut . | 3 | 64 | 19 | 369 | | | 16 | 712 | 4,380 |
| Fourth . | 25 | 310 | (Perennial) | | 274 | 2,740 | 47 | ... | 391 |
| Barrage . | (Classed as perennial) | | | | | | (Perennial) | | 8,095 |
| Total . | 104 | 4247 | 20 | 385 | 740* | 11,740 | 3778 | 1250 | 40,631 |

* Aswan 16, Kena 54, Girga 110, Assiut 286, Minia 150, Beni Suef 24, Giza 100.

In 1897 it was estimated that the total number of water-wheels or sakias on wells in the basins was 17,340; in 1912 it is estimated that there are 40,600. In 1897 there were no oil engines on wells in the basins; to-day there are 740 with a joint I.H.P. of 11,740. This means a utilisation of the subsoil water in the basins during summer, which, if continued, will make the basins independent of perennial irrigation from canals excavated purposely for such irrigation.

The area irrigated by all these engines and sakias is very large, and may be thus subdivided :—

| Circle of Irrigation. | Total Area in acres. | Area in acres Irrigated in Summer in the Basin Tracts. | | | | |
|---|---|---|---|---|---|---|
| | | Cotton. | Sugar-cane. | Summer Sorghum. | Flood Sorghum. | Total. |
| Fifth | 440,300 | 4,700 | 21,620 | 25,470 | 51,000 | 102,790 |
| Girga | 435,250 | 1,450 | 2,060 | 41,730 | 18,390 | 63,630 |
| Assiut | 224,506 | 700 | 10,100 | 17,960 | 2,650 | 31,410 |
| Fourth | 134,579 | 2,000 | 1,000 | 8,000 | 20,000 | 31,000 |
| Barrage | 52,000 | 2,000 | 500 | 4,000 | 5,000 | 11,500 |
| Total | 1,286,635 | 10,850 | 35,280 | 97,160 | 97,040 | 240,330 |

The figures for the three upper circles were supplied by the Inspectors. For the two lower circles the figures for basin and perennial irrigation were sent together, and we have calculated, from analogy and other information at our disposal, the approximate areas of summer irrigation in the basin tracts. In the basin tracts of the Fifth Circle the double cropped area amounts to one-fourth of the whole area. In some of the perennially irrigated tracts, the double cropped area only amounts to one-third of the whole area.

53. **Extent and Cost of Works to ensure Basin Irrigation.**—We have seen that the total area still considered as irrigated by basins is 1,286,635. To ensure the irrigation of this tract the public works constructed and maintained are the following:—

| Name of Work. | | Fifth Circle. | Girga Circle. | Assiut Circle. | Fourth Circle. | Barrage Circle. | Total. |
|---|---|---|---|---|---|---|---|
| Nile Banks | Kilometres | 436 | 241 | 198 | ... | ... | 875 |
| Basin banks | " | 959 | 1131 | 365 | 369 | 125 | 2949 |
| " canals | " | 1668 | 1649 | 331 | 129 | 100 | 3877 |
| " drains | " | 71 | 143 | 38 | 7 | ... | 259 |
| " escapes | Number | 32 | 17 | 17 | 18 | 2 | 86 |
| " regulators | " | 402 | 397 | 82 | 33 | 11 | 925 |
| " syphons | " | 20 | 26 | 9 | 2 | ... | 57 |

The cost of these works at existing rates may be thus estimated as a matter of curiosity :—

| | | | | |
|---|---|---|---|---|
| Nile banks | 900 kilometres at | | £400 = | £360,000 |
| Basin „ | 3000 | „ | 600 = | 1,800,000 |
| „ canals | 4000 | „ | 600 = | 2,400,000 |
| „ drains | 250 | „ | 120 = | 30,000 |
| „ escapes | 90 | „ | 2500 = | 225,000 |
| „ regulators | 900 | „ | 1000 = | 900,000 |
| „ syphons | 60 | „ | 3000 = | 180,000 |
| Land—40,000 acres | | „ | 50 = | 2,000,000 |
| | Total . . . | | | £7,895,000 |

This represents a sum of £6 per acre.

The annual maintenance charges of the Fifth and Girga Circles, which are wholly basin irrigation, amount to £96,000 for 875,000 acres, or about 11 piastres per acre. In the remaining three circles the basin and perennial expenditure is not kept separate; but if we apply the same rate as in the Fifth and Girga Circles, £·11 per acre per annum, we obtain the following figures :—

| | | Maintenance Charges per annum. |
|---|---|---|
| Fifth Circle . . . . | 440,300 acres | £53,000 (actual) |
| Girga „ . . . . | 435,250 „ | 43,000 „ |
| Assiut „ . . . . | 224,506 „ | 25,000 (calculated) |
| Fourth „ . . . . | 134,579 „ | 15,000 „ |
| Barrage „ . . . . | 52,000 „ | 6,000 „ |
| Total . . . . | 1,286,635 „ | £142,000 |

M. J. Barois, in his *Les Irrigations en Egypte*, published in 1904, gives the following interesting information about the cost of maintenance of basin works :—

" With a total basin area of 1,730,000 acres the amount of earthwork executed annually is 7,110,000 cubic metres, thus subdivided :—

| | Cubic metres. | Per cent. |
|---|---|---|
| Repairs to banks . . . . | 3,020,000 | 42 |
| Silt clearance . . . . | 3,840,000 | 54 |
| Repairing breaches . . . | 210,000 | 3 |
| Temporary dams . . . | 40,000 | 1 |

In the Fifth Circle the silt clearance is 73 per cent., and the bank repairs 25 per cent., while in the Fourth Circle the silt clearance is 5 per cent., and the bank repairs 85 per cent."

54. **Improvements during the last Fifteen Years.**—Improvements are annually made in the basins on the broad lines of Colonel Ross's recommendations. The length of bank protected by stone revetment to

stand the wash of the waves is gradually being increased, while the old protected reaches are maintained in good working order. Minor regulators to perfect the method of filling and emptying the basins are being steadily increased. Masonry and iron bridges across the canals are annually added to, and communications are thus improved. Many of the basins are subdivided into smaller compartments to ensure a better supply of the rich red waters of the Nile flood reaching every individual field. An increasing use is being made annually of the subsoil water underlying the whole Nile Valley. Indeed, where fifteen years ago first-class basin land was worth from £50 to £60 per acre, to-day it is worth from £100 to £120 per acre. Girga Province, the centre of basin irrigation, is more densely populated and more prosperous than even Menufia, the centre of perennial irrigation. Indeed, a basin which possesses good subsoil water could have its area perennially irrigated and planted with cotton or sugar for a year or two and then irrigated as a basin for a year. This would be the ideal irrigation of the world.

The basins most difficult to irrigate well at all times or to irrigate at all in a low year were those of the Fifth Circle in Kena Province. Their irrigation has been greatly improved by the construction of the Esna Barrage, which can hold up 2 metres of water in flood and so convert a low year into one of plentiful supply. If this barrage were provided with a subsidiary weir like the Delta Barrage, and the water could be held up to a height of 4 or 5 metres in winter, the prosperity of the country served by the barrage would be greatly enhanced, and the water supply might even be sent down to Girga Province.

Upper Egypt also needs a barrage near the boundary between the Kena and Girga Provinces, which would ensure perfect flood irrigation to Girga and Assiut Provinces even if water were held back in the Sudan from the 15th September for reservoir purposes. The same barrage provided with a subsidiary work would supply winter water to the same two provinces.

The Walidia system of basin downstream of Assiut and between the Ibrahimia Canal and the Nile was deprived of its supplies of flood water from the Sohagia Canal when the Ibrahimia Canal was constructed in 1874. A syphon has been recently constructed under the Ibrahimia Canal to rectify this. This syphon should be doubled.

The lands to the west of the Yusufi Canal in Minia and Beni Suef Provinces have been provided with basin banks, canals, and escapes, and very greatly improved.

When the basins on the left bank of the Nile were converted to perennial irrigation, the tracts west of the Yusufi Canal were left under basin and flood irrigation in order to prevent the desert sand, under the action of the prevailing north-west winds, from overwhelming the country.

This work might be supplemented by extensive plantations of tamarisks, date-palms, liquorice, and wattles; otherwise the silt clearances of the boundary drain will continue to be a very serious item in the maintenance budget. The leguminous thorn, so common to the Euphrates delta and in Cyprus, might answer admirably here.

Mr Back, with the aid of subsoil water lifted by small oil-engine pumps, has reclaimed quite an extensive reach of desert and covered it with valuable date-palms near the Pyramids. He has introduced the Diglet-el-Nûr dates from Tunis.

55. **List of Basin Canals.**

TABLE 167.—FIFTH CIRCLE BASIN CANALS.

| Left Bank of the Nile. | | | Right Bank of the Nile. | | |
|---|---|---|---|---|---|
| Name of Canal. | Bed Width at Head in metres. | R.L. of Bed. | Name of Canal. | Bed Width at Head in metres. | R.L. of Bed. |
| Banban | 5·00 | 86·90 | Khattâra | 3 | 89·45 |
| Ramâdi | 16·00 | 82·00 | Daraw | 3 | 87·13 |
| Naziria | 20·00 | 81·00 | Eglît | 2 | 85·79 |
| Shamakia | 12·00 | 80·00 | Selwa | 3 | 83·73 |
| Asfûn | 18·00 | 76·00 | Ridisia | 4 | 82·71 |
| Fadilia | 12·00 | 73·00 | Old Kilabia | 1 | 77·50 |
| Tukh | 11·00 | 70·75 | New Kilabia | 18 | 76·50 |
| Rannan | 15·00 | 66·90 | Bayadia | 14 | 73·40 |
| Damrania | 16·00 | 64·25 | Shanhuria | 15 | 70·90 |
| Rashwania | 9·00 | 63·50 | Sheikhia | 3 | 71·00 |
| Rakaik | 5·00 | 64·80 | Khor Kena | 20 | 68·84 |
| Homrania | 3·00 | 64·25 | Samata | 10 | 68·25 |
| | | | El Kasr | 5 | 66·60 |

TABLE 168.—GIRGA CIRCLE BASIN CANALS.

| Left Bank of the Nile. | | | Right Bank of the Nile. | | |
|---|---|---|---|---|---|
| Name of Canal. | Bed Width at Head in metres. | R.L. of Bed. | Name of Canal. | Bed Width at Head in metres. | R.L. of Bed. |
| Rashwania | 18·00 | 63·46 | Tarif | 10·00 | 64·70 |
| Kasra | 21·00 | 61·04 | Hawis | 13·00 | 63·70 |
| Zarzuria | 17·00 | 61·40 | Awlâd Yahia | 7·00 | 62·72 |
| Um Tubul | 5·00 | 62·23 | Lahaiwa | 10·00 | 59·40 |
| Girgawia | 18·00 | 59·50 | Isawia | 14·00 | 57·50 |
| Hewêti | 7·00 | 57·43 | Khazindaria | 18·00 | 52·50 |
| Sohagia | 70·00 | 56·50 | | | |
| Tahtawia | 15·00 | 56·34 | | | |
| Shattûra | 9·00 | 53·60 | | | |

TABLE 169.—ASSIUT BARRAGE CIRCLE BASIN CANALS.

| Left Bank of the Nile. | | | Right Bank of the Nile. | | |
|---|---|---|---|---|---|
| Name of Canal. | Bed Width at Head in metres. | R.L. of Bed. | Name of Canal. | Bed Width at Head in Metres. | R.L. of Bed. |
| *From the Nile—* | | | | | |
| Ibrahimia | 50·00 | 43·50 | Maana | 10·00 | 49·00 |
| Beni Hussein | 4·00 | 48·02 | Sunt | 5·00 | 49·50 |
| Beni Shegair | 1·00 | 45·90 | Maabda | 5·00 | 47·34 |
| *From the Ibrahimia—* | | | | | |
| Waladia | 4·00 | 49·50 | Maraona | 2·00 | 47·23 |
| Masara | 5·00 | 46·50 | Dêr Kusseir | 1·00 | 44·20 |
| Maharrak | 5·00 | 46·00 | Hawata | 1·50 | 41·90 |
| Kosia | 3·00 | 44·50 | Birsha | 1·50 | 40·70 |
| Delgawi | 6·00 | | Sheikh Ebada | 2·00 | 40·00 |

TABLE 170.—FOURTH CIRCLE BASIN CANALS.

| Left Bank of the Nile. | | | Right Bank of the Nile. | | |
|---|---|---|---|---|---|
| Name of Canal. | Bed Width at Head in Metres. | R.L. of Bed. | Name of Canal. | Bed Width at Head in Metres. | R.L. of Bed. |
| Girza | 20·00 | 19·90 | None | | |

## 56. Dates of Filling and Emptying Basins.—

TABLE 171.—DATES OF FILLING AND EMPTYING BASINS.

| Year. | Dates of Opening Canals. | Dates of Beginning the Discharge of the Basins. |
|---|---|---|
| | *Fifth Circle.* | |
| 1898 | August 10 | October 1 |
| 1899 | 10 | September 30 |
| 1900 | 10 | October 5 |
| 1901 | 15 | 1 |
| 1902 | 14 | 10 |
| 1903 | 11 | 8 |
| 1904 | 10 | 3 |
| 1905 | 12 | 5 |
| 1906 | 10 | 3 |
| 1907 | 13 | 3 |
| 1908 | 12 | 16 |
| 1909 | 5–22 | 9 |
| 1910 | 7–15 | 9 |
| 1911 | 7–20 | 8 |

| Year. | Dates of Opening Canals. | Dates of Beginning the Discharge of the Basins. |
|---|---|---|
| | *Girga Circle.* | |
| 1898 | August 8–17 | October 1–18 |
| 1899 | 9–15 | Sept. 30 to Nov. 12 |
| 1900 | 10–15 | October 5–22 |
| 1901 | 10–13 | 5–17 |
| 1902 | 11–20 | Oct. 6 to Nov. 6 |
| 1903 | 10–15 | October 3–10 |
| 1904 | 11–15 | 2–26 |
| 1905 | 13–22 | 2–30 |
| 1906 | 13–17 | 4–17 |
| 1907 | 11–15 | Oct. 1 to Nov. 10 |
| 1908 | 10–21 | October 5–24 |
| 1909 | 10–16 | 6–21 |
| 1910 | 12–17 | 5–21 |
| 1911 | 12–18 | 5–18 |

TABLE 172.—BASIN IRRIGATION OPERATIONS.

| Year. | Sohagia Canal. | | Abutig Escape. | Delgawi. | | Dêr Sankiria Escape. | Niklai Escape. | Om Dinar Escape. |
|---|---|---|---|---|---|---|---|---|
| | Opened. | Closed. | Opened. | Canal Opened. | Escape Opened. | Opened. | Opened. | Opened. |
| 1898 | August 12 | October 27 | October 3–10 | August 15 | October 11 | ... | October 29 | |
| 1899 | 15 | 25 | Oct. 30 to Nov. 5 | 15 | 19 | ... | November 30 | |
| 1900 | 12 | 15 | October 17 | 11 | 10 | ... | 18 | |
| 1901 | 12 | 20 | 26 | 15 | 17 | November 3 | 11 | |
| 1902 | 17 | 13 | 12 | 30 | 10 | 28 | 10 | |
| 1903 | 13 | 5 | 30 | 23 | 5 | 1 | 9 | |
| 1904 | 13 | November 1 | November 7 | 24 | 14 | 3 | 23 | November 27 |
| 1905 | 16 | Oct. 21 to Nov. 3 | 2 | 25 | 19 | 14 | 29 | December 3 |
| 1906 | 15 | October 7 | October 19 | 13 | 10 | 12 | 1 | November 4 |
| 1907 | 15 | November 9 | November 11 | September 4 | 30 | 23 | 4 | December 10 |
| 1908 | 15 | October 9 | October 23 | August 5 | 9 | 15 | 7 | November 11 |
| 1909 | 15 | 23 | 25 | 25 | 10 | 14 | 7 | December 7 |
| 1910 | 18 | 27 | 5 | September 2 | 9 | 15 | 13 | November 1 |
| 1911 | 15 | 23 | 5 | August 27 | 10 | 15 | 21 | 25 |

57. **Notes on the Fifth Circle of Irrigation.**—Mohamed Shefîk Bey, Inspector, Fifth Circle, writes as follows:—

"The figures in the following table were taken from the figures given by the Mudirias for winter and summer cultivation in the Fifth Circle during the last three years."

| Year. | Province. | Winter Crops in acres. | Summer Cultivation in acres. | | | | |
|---|---|---|---|---|---|---|---|
| | | | Vegetables. | Millets. | Cotton. | Sugar-cane. | Total. |
| 1909 | Aswan | 92,439 | 2961 | 2,720 | 215 | 354 | 6,250 |
| | Kena | 347,861 | 1929 | 26,642 | 1785 | 13,500 | 43,856 |
| | Total | 440,300 | 4890 | 29,362 | 2000 | 13,854 | 50,106 |
| 1910 | Aswan | 94,227 | 2615 | 2,992 | 70 | 822 | 6,499 |
| | Kena | 348,570 | 2163 | 23,624 | 2907 | 15,914 | 44,608 |
| | Total | 442,797 | 4778 | 26,616 | 2977 | 16,736 | 51,107 |
| 1911 | Aswan | 93,768 | 2094 | 2,588 | 770 | 3,380 | 8,832 |
| | Kena | 346,627 | 1687 | 22,885 | 3935 | 18,239 | 46,746 |
| | Total | 440,395 | 3781 | 25,473 | 4705 | 21,619 | 55,578 |

The area under vegetables and melons is decreasing, owing to the inundation of the crops cultivated on the river foreshores by the Aswan Reservoir water during the summer.

There is a decrease in the cultivation of millets, and an increase in cotton and sugar-cane.

The Société Générale des Sucreries de la Haute Egypte has the following Sugar Factories at Armant and Naga Hammadi:—

| Name of Factory. | Year 1909. | | | Year 1910. | | | Year 1911. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sugar-cane delivered to Factory. | Sugar extracted. | Sugar per ton of Cane. | Sugar-cane delivered to Factory. | Sugar extracted. | Sugar per ton of Cane. | Sugar-cane delivered to Factory. | Sugar extracted. | Sugar per ton of Cane. |
| | tons. | tons. | kilo. | tons. | tons. | kilo. | tons. | tons. | kilo. |
| Naga Hammadi | 118,195 | 11,738 | 99 | 122,053 | 13,406 | 109 | 161,835 | 17,923 | 111 |
| Armant | 103,301 | 10,503 | 101 | 108,956 | 12,527 | 115 | 121,350 | 13,300 | 109 |
| Total | 221,496 | 22,241 | 100 | 231,009 | 25,933 | 112 | 283,185 | 31,223 | 110 |

The other factories of Matana and Daaiya are not working now.

A third factory was constructed at Kom Ombo in 1911 and inaugurated in January 1912.

The sugar extracted from the ton of cane varies from 99 kilograms to 115.

The comparison of the area cultivated in cane with the amount of sugar extracted shows that one acre gives 1·66 tons of sugar.

There are in this circle 48 artesian pumps of diameters varying from 4 to 16 inches, irrigating 3500 acres. They are able to water 13,400 acres, but their owners failed to come to terms with the fellahin who own the lands.

The figures in the following table have been kindly given me by the Upper Egypt Irrigation Co.'s agent at Deshna for their artesian pumps:—

| Diameter of Pump in inches. | I.H.P. per one metre Lift. | Discharge in cubic metres per hour. |
|---|---|---|
| 6 | 1·5 | 170– 250 |
| 8 | 3·0 | 360– 450 |
| 10 | 4·5 | 575– 700 |
| 12 | 6·5 | 900–1100 |
| 14 | 8·5 | 1100–1350 |
| 16 | 11·0 | 1400–1800 |
| 18 | 15·0 | 2000–2500 |

*Example.*—It is required to irrigate 500 acres in summer by an artesian well, lift being 9 metres. What should be (Fifth Circle of irrigation)

First, the diameter of the pump,

Second, the power of the engine?

*Answer.*—As the 500 acres should be irrigated in twelve days, and 800 cubic metres of water are required for one watering, the discharge per hour should be

$$\frac{500}{12} \times 800 \times \frac{1}{24} = 1400 \text{ cubic metres.}$$

From the table, a pump of 16 inches will answer; and, the power of the engine per metre of lift being 11 I.H.P., the power should be

$$11 \times 9m = 99 \text{ I.H.P.}$$

I found that the figures of this table show that the relation between the diameter D of a pump in inches, the lift H in metres, and the I.H.P., P is

$$P = \frac{1}{22} D^2 H$$

(H includes both suction and delivery heights).

From a comparison made of the diameter of pumps actually erected on the river with the maximum area which can be watered, in good condition during the summer, I found that if D is the diameter in inches and F the area in acres, there is this relation :

$$F = 2D^2.$$

*Example.*—10-inch pump can maintain $2 \times 10^2 = 200$ acres of summer cultivation in the Fifth Circle in good condition.

Also the discharge Q per hour equals $5·33D^2$, *i.e.* the discharge of the 10-inch pump per hour is $5·33 \times 100 = 533$ cubic metres. The average lift in this circle is 8 metres."

"In the report for 1908 Mr Langley, Inspector-General of Irrigation, Upper Egypt, writes thus about the Esna Barrage:—

'The object of the Esna Barrage is to raise the water level in flood and so irrigate lands which in years of low supply are left sharaki (*i.e.* unirrigated), and ultimately to act like the Assiut Barrage when more water is available from the Upper Nile.

'In order to utilise this rise of level, main canals on the east and west of the river to feed the basins were necessary.

'The area that will derive direct benefit from the Esna Barrage by means of the two main canals is approximately 171,000 acres, of which 71,000 lie on the east of the Nile and 100,000 on the west. In addition to the area mentioned above, the remaining portion of Kena Province will benefit indirectly, as the extra water supplied to the southern systems will be available for passing on and completing irrigation to the north.

'In designing the main canals a water level of R.L. 81·00 metres was taken. This corresponds to R.L. 92·00 or 14½ pics at Aswan, with the Esna Barrage holding up 1·50 metres.

'The Aswan gauge diagram shows that the mean gauge of thirty years for forty-five days is above that level; and therefore it is only in exceptional years like 1902 and 1907 that this level will be difficult to obtain even by regulation on the barrage.

'Taking the levels at Aswan in 1907, the maximum was 91·48 on the 3rd September: this will give a level of only 80·63 at Esna with a calculated head of 1·50.

'It appears from calculations that in an exceptionally bad Nile like 1907, it will be possible to obtain a level of from 90·20 to 89·65 during the filling season. This will not give the required level in the basins immediately adjoining the barrage, but an arrangement is being made for completing the irrigation of these basins from the Ramâdi Canal on the west.'

All summer irrigation in this circle is done by lift, such as shadufs, sakias, and pumps, which are all private property.

The most important of these stations, three in number, are situated as follows:—

(1) At Kom Ombo, Aswan province, to irrigate the Kom Ombo estates. The pumps and lands are owned by the same company.

There are 22,000 acres actually cultivated by three pumps of 0·80 metre diameter worked by three fixed engines of 1500 I.H.P. each. The average height of lift is about 15 metres during flood and about 23·0 metres during the summer.

(2) and (3). At El Derb and El Khoderat both are in Naga Hammadi District, Kena Province, owned by the Société égyptienne d'irrigation which supplies water to irrigate the fellahin's lands.

| Locality. | Indicated H.P. | Number of Pumps. | Diameter of Pumps in metres. | Height of Lift in | |
|---|---|---|---|---|---|
| | | | | Summer. Metres. | Flood. |
| El Derb . . . | 760 | 2 | 0·80 | 8·0 | stopped |
| El Khoderat . . | 890 | 2 | 1·20 | 8·0 | ,, |

The following table gives the quantity of water lifted by these three pumps during the summer of 1911 and the duty per acre per day. It is the custom to water the fields once every twelve days.

| | March. | April. | May. | June. | July. | August. |
|---|---|---|---|---|---|---|
| Kom Ombo— | | | | | | |
| Discharges . . | 17·4 | 7·5 | 4·9 | 8·7 | 17·7 | 17·8 |
| Area watered . | 18,900 | 6,400 | 6,400 | 6,400 | 6,400 | 6,400 |
| Duty . . . | 30 | 40 | 30 | 45 | 89 | 89 |
| El Derb— | | | | | | |
| Discharges . . | 3·8 | 5·4 | 7·1 | 10·3 | 10·7 | 15·4 |
| Area watered . | 4,000 | 4,400 | 5,100 | 5,100 | 7,400 | 7,400 |
| Duty . . . | 31 | 47 | 47 | 47 | 47 | 67 |
| El Khoderat— | | | | | | |
| Discharges . . | 7·9 | 11·2 | 14·9 | 12·9 | 15·5 | 21·8 |
| Area watered . | 4,300 | 5,900 | 6,800 | 6·800 | 9,000 | 9,000 |
| Duty . . . | 59 | 63 | 66 | 62 | 56 | 77 |
| Average duty . | 40 | 50 | 48 | 51 | 64 | 73 |

Discharges are in millions of cubic metres per month.
Areas watered in acres.
Duty, cubic metres of water per acre per day."

Shefik Bey adds this note on the quantity of water used in the flood of 1911 for basin supply in the Kilabia and Asfun systems of basins :—

"*Asfun Canal.*—The total quantity of water entering this canal was 373 millions of cubic metres; from this quantity 20 millions must be deducted as it was escaped into the Fadilia system, leaving 353 millions for the Asfun system itself.

The area served was 45,270 acres; therefore the duty per season per acre was

$$\frac{353,000,000}{45,270} = 8000 \text{ cubic metres.}$$

*Kilabia Canal.*—The amount of water entering this canal was 319·8 millions; deducting 34·6 which was escaped into the Bayadia System, the remainder is 285·2 millions.

The area served was 26,230; therefore the duty per season per acre was

$$\frac{285,000,000}{26,230} = 10,800 \text{ cubic metres.}$$

This figure has been hitherto taken as 4000.

This was computed from an allowance of one metre of water over the ground.

The idea was right; but to give one metre of water over the ground another depth of one metre must be allowed to enter the basin for evaporation and absorption."

58. **Notes on the Girga Circle of Irrigation.**—The following notes were supplied by Mohamed Bey Sidky, the Inspector :—

TABLE 173.—DETAILS OF SUMMER AND FLOOD CROPS IN THE BASINS, FORESHORES, AND ISLANDS.

| Province. | Total Area in Basins. | Cotton. | Sugar-cane. | Flood Sorghum. | Summer Sorghum. | Total Area in Foreshores and Islands. | Cotton. | Sugar-cane. | Flood Sorghum. | Summer Sorghum. |
|---|---|---|---|---|---|---|---|---|---|---|
| Girga . . | 222,160 | 1250 | 1883 | 3890 | 40,222 | 33,643 | 103 | 540 | 9,781 | 838 |
| South Assiut . | 113,786 | 217 | 312 | 2807 | 8,852 | 10,765 | 34 | 138 | 1,997 | 236 |
| Total . | 335,946 | 1467 | 2195 | 6697 | 49,074 | 44,408 | 137 | 678 | 11,778 | 1074 |

*Note.*—The areas under summer and flood crops are approximate.

[TABLE

TABLE 174.—GIRGA CIRCLE IRRIGATION. DATES OF OPENING MAIN CANALS.

| Name of Canal. | Year 1898. | Year 1899. | Year 1900. | Year 1901. | Year 1902. | Year 1903. | Year 1904. | Year 1905. | Year 1906. | Year 1907. | Year 1908. | Year 1909. | Year 1910. | Year 1911. | System. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tarif | Aug. 17 | Aug. 13 | Aug. 11 | Aug. 10 | Aug. 19 | Aug. 15 | Aug. 12 | Aug. 21 | Aug. 16 | Aug. 11 | Aug. 15 & 16 | Aug. 11–12 | Aug. 15 and 16 | Aug. 15 | Khyam | On the right bank of the river. |
| Hawis | 12 | left open | 10 | 13 | 17 | 15 | 13 | 22 | 15 | 11 | 12 | 11–16 | 15 | 14 | Khyam | On the right bank of the river. |
| Lahaiwa | 9 | ,, | 12 | 10 | 20 | 13 | 15 | 20 | 10 | 11 | 12 | 10–14 | 13 and 14 | 15 | Akhmim | On the right bank of the river. |
| Isawia | 8 | 10 | 10 | 10 | 15 | 10 | 11 | 13 | 10 | 11 | 10 | 10–11 | 14 | 12 | Akhmim | On the right bank of the river. |
| Khazindaria | 10 | 10 | 10 | 10 | 11 | 13 | 11 | 15 | 17 | 14 | 12 | 15 | 14 | 18 | Badari | On the right bank of the river. |
| Menna | 10 | 10 | 10 | 10 | 12 | Early in this year the Abnub system was transferred to the Assiut Barrage Circle. | ... | ... | ... | ... | ... | ... | ... | ... | Abnub | On the right bank of the river. |
| Sunt | 10 | 10 | 10 | 10 | 14 | | | | | | | | | | Abnub | |
| Ali Bey | 10 | 13 | 15 | 10 | not opened | | | | | | | | | | Abnub | |
| Mabda | 9 | 15 | 15 | 10 | ,, | | | | | | | | | | Abnub | |
| Rashwania | 17 | 12 | 11 | 12 | 19 | 12 | 15 | 16 | 17 | 12 | 13 | 12–14 | 15 and 16 | 15 | | On the left bank of the river. |
| Kasra | 15 | 10 | 12 and 15 | 10 | 14 | 13 | 14 | 16 | 14 | 11 | 13–16 | 11–14 | 15 and 16 | 15 | | On the left bank of the river. |
| Zarzuria | 13 | 12 | 10 | 10 | 15 | 10 | 15 | 17 | 17 | 13 | 13 | 10–14 | 16 | 15 | | On the left bank of the river. |
| Um el Tubul | Joined on to the Rashwania Canal. | | | | | | | | | | 17* | 25 | Sept. 2 | Sept. 3 | | On the left bank of the river. |
| Girgawia | 11 | 12 | 10 | 10 | 13 | 10 | 14 | 15 | 16 | 12 | 13 | 10–12 | Aug. 16 and 17 | Aug. 14 | | On the left bank of the river. |
| Sohagia | 12 | 15 | 12 | 12 | 17 | 13 | 13 | 15 and 17 | 15 | 15 | 15 | 15 | 18 | 15 | | On the left bank of the river. |
| Heweiti | 12 | 12 | 12 and 14 | 10 | 17 | 14 | 12 | 17 | 15 | 13 | 21 | 13 | 15 | 15 | | On the left bank of the river. |
| Tahtawia | 12 | 9 | 12 | 11 | 14 | 12 | 13 | 15 | 13 | 12 | 13 | 11–15 | 15 and 16 | 14 | | On the left bank of the river. |
| Shattura | 13 | 10 | 12 | 12 | 15 | 10 | 11 | 15 | 15 | 13 | 12 | 14 | 12 | 14 | | On the left bank of the river. |

* A new head regulator was built for the admission of red water direct from the Nile.

TABLE 175.—DATES OF GENERAL DISCHARGE OF BASINS.

| Date. | Girga and South Assiut. Left Bank of River. | Girga and South Assiut. Right Bank of River. | Sohagia Canal closed. | Sohag Escape opened. | Abu Tig Escape opened. | Remarks. |
|---|---|---|---|---|---|---|
| 1898 | Between Oct. 1 and 18 | Between Oct. 2 and 8 | October 27 | October 1 | Between Oct. 3 and 10 | |
| 1899 | Sept. 30 and Nov. 12 | Sept. 28 and Nov. 22 | 25 | not opened | 30 and Nov. 5 | |
| 1900 | Oct. 5 and 22 | Oct. 5 and 17 | 15 | October 17 | October 17 | |
| 1901 | 5 and 17 | 5 and 13 | 20 | 23 | 26 | |
| 1902 | 1 and Nov. 6 | 6 and Nov. 12 | 13 | 27 | 12 | Abnub system included. |
| 1903 | 3 and 20 | 3 and 15 | 5 | 26 | 30 | Abnub system separated. |
| 1904 | 2 and 26 | Sept. 29 and Oct. 27 | November 1 | November 1 | November 7 | |
| 1905 | 2 and 30 | Oct. 1 and 29 | Between Oct. 21 and Nov. 3 | 3 | 2 | |
| 1906 | 4 and 17 | 3 and 14 | October 7 | October 27 | October 19 | |
| 1907 | 1 and Nov. 10 | Sept. 30 and Nov. 2 | November 9 | November 8 | November 11 | |
| 1908 | 5 and 24 | Oct. 7 and 22 | October 9 | October 28 | October 23 | |
| 1909 | 6 and 21 | 6 and 17 | 23 | 28 | 25 | |
| 1910 | 5 and 20 | 6 and 20 | 27 | 24 | 5 | |
| 1911 | 5 and 18 | 6 and 14 | 23 | Between Oct. 8 and 22 | 5 | |

59. **Notes on the Assiut Barrage Circle.**—The following notes were supplied by Mr G. T. Brooke, the Inspector :—

"In a normal flood all the basins are brought up to full supply in forty days :—

| Name of System. | Area in acres of the Basins alone. | Quantity of Water to fill the Basins in millions of cubic metres. | Discharge for forty days in millions of cubic metres per day. | Discharge per second for forty days. |
|---|---|---|---|---|
| Abnub . . . | 48,370 | 249·7 | 6·24 | 72·2 |
| West of Ibrahimia . | 123,939 | 890·2 | 22·25 | 257·5 |
| East of Ibrahimia . | 24,697 | 151·4 | 3·78 | 43·7 |
| Total . | 197,006 | 1291·3 | 32·27 | 373·4 |

The above includes evaporation losses of 8 millimetres per day over forty days—say, 30 centimetres ; but does not include absorption losses.

Perfectly dry silt will absorb 53 per cent. of water. Assuming the spring level to be 4 metres below the surface at the beginning of the flood, the dampness may be assumed to vary from 0 at surface to saturation. As this variation is not uniform, instead of taking $\frac{53}{2}$ as the mean absorptive power of the soil, 15 per cent. is probably a nearer figure and equals a depth of 60 centimetres.

197,000 acres of 4200 square metres × ·60 metre = 496·4 millions of cubic metres to saturate the soil = 12·4 millions cubic metres per day for forty days = 143·4 cubic metres per second for forty days. Therefore the total quantity of water taken by the above basins will be in a normal flood 1787·7 millions of cubic metres in forty days, or 44·7 millions of cubic metres per day for forty days, or 517·2 cubic metres per second for forty days. The amount used on the foreshores is presumably about the mean duty of lift water, say 30–35 cubic metres per acre per day, supposing them to be not flooded.

I have no record of the amount of water discharged by the basins ; it might be assumed to be :—

1291·3 millions of cubic metres, less 30 centimetres evaporation during filling from 15th August to 25th September, and less 15 centimetres evaporation during the time of staying full and being discharged from 25th September to 25th October, or 45 centimetres × 197,000 × 4200, or 372·3 millions of cubic metres, leaving 919 millions of cubic metres to be discharged, or say 900 millions.

Discharge in this circle begins on 10th October and is over by 5th November, *i.e.* in twenty-five days. That gives 36 million cubic metres per day or 416 cubic metres per second for twenty-five days.

The figures given above are based on calculation, and not on discharges taken.

The present quantity of water required during forty days' filling is 517·2 cubic metres per second. If all the basins were converted to perennial irrigation, there would be a diminution of 121·2 cubic metres per second, leaving 396 cubic metres per second. With a good flood the basins would be filled by 20th September, and 396 cubic metres per second would raise the river level about 15 centimetres, depending on the gauge."

60. **Notes on the Fourth Circle of Irrigation.**—The following note was written by Mr H. Molesworth, the Inspector of the Fourth Circle of Irrigation.

"The programme now adopted for filling the west Yusufi basins has become (after some years of trial and also modification due to changes in the basin and perennial area carried out by the Conversion Works) more or less stereotyped, and briefly is as follows:—

As soon as the rising flood produces levels sufficient to give discharges satisfying perennial needs, the Yusufi Canal begins to take the excess of the Ibrahimia Canal discharge—usually early in August.

Heading up is then begun on Nazlet Abid regulator and the level raised to 20 centimetres short of the full supply (R.L. 40·80), the D.S. level being allowed to rise gradually till the next regulator, Sagula, obtains a level of 33·70 upstream; whilst the downstream level is not allowed to rise beyond R.L. 32·00, on account of the drainage escape at Abu Rahib, where the western Moheit discharges into the Yusufi. Heading up then begins on Mazura regulator until the upstream level reaches R.L. 30·40, and the downstream level is kept at R.L. 29·00 to allow of efficient drainage from the Central Moheit system from Talt into the Yusufi.

The basins depending on the three above-mentioned regulators are gradually brought up to within 0·50 metre of full supply; and as soon as the Assiut basins are opened, the chains are quickly brought up to their full supply levels. The downstream levels of the regulators are allowed to rise in turn as the process continues northwards.

Lahun regulator then gradually rises to its maximum of R.L. 27·20, a rise beyond this being checked by the Abu Bakr escape.

Hager Koshesha and Magrur Koshesha basins are then brought up to their full supply levels.

Rikka Basin is now being brought to full supply through the Ebweit regulators (two) out of the Giza Canal, and by feeding across it, through the Giza Canal escape at Abu Shekuk out of the Magrur Koshesha.

Komi regulator is opened to allow Moarkab and Tahma to obtain their full supply levels, the Girza Feeder being shut.

This completes the filling process.

The escapes of the three basin chains at Deir el Sanguria, Shinera, and Manshiet el Hagg are opened and the basins are run off into the Yusufi; the rate of escapage being controlled by certain maximum levels not to be exceeded in the Yusufi. One after the other, the Nazlet Abid, Sakula, and Mazura regulators have their regulation taken off, the rate at which this is done being controlled by maximum downstream levels.

Abu Bakr escape is opened up and the water of the Yusufi and Magrur Koshesha passed out at the old Koshesha escape. Only twenty of the original sixty openings are now needed for present-day operations. The controlling factor in the discharge of the basins is the level of the Nile, and should the river have dropped away quickly, a rapid discharge is only controlled by the fact that too rapid drainage off the basins is injurious, since it carries with it the fine silt and slime deposited by the water.

Hager Koshesha basin is discharged through a pipe escape into the Rikka basin,

and the Rikka basin can be discharged out into the Nile back through the Girza head and on through Moarkab and Tahma basins. These last are finally discharged at Tahma regulator into Dahshur basin."

61. **Selection from the Irrigation Report for 1894.**—In the report on the very high flood of 1894, Sir R. Hanbury Brown wrote as follows:—

"As in 1892, it was judged advisable to fully open the Koshesha escape early to avoid the risk of obtaining excessive levels in the basin, which might have endangered the stability of the banks; for, if the Koshesha cross-bank were to breach when the basin was at high level, the effect on the Giza province, and probably on Cairo itself, would be disastrous. A sudden rise in both the Damietta and Rosetta branches would also be caused, which might result in a breach of the Nile bank in Lower Egypt.

The operation of opening the escape extended over six days, ten of the upper gates being let go daily, commencing on the 27th September.

The Inspector of Irrigation, Fourth Circle, received instructions at the end of September to be prepared to open Dalgawi escape on the 13th October, but to commence lowering the basins between Assiut and Deirût from the 5th October, by shutting off their heads, keeping, however, Dalgawi basin full.

It was also arranged that the Fifth Circle and Girga Directorate should commence to discharge on the 5th October, by gradually opening the tail escapes and closing canal heads not already closed, so that all escapes might be fully open and all canal heads closed by the 15th October; with the exception of Araba and Gharîzât basins on the west of the Sohagia, which were to commence their discharge on the 3rd October, while the Sohagia was still high, so that the rate of discharge might not be too rapid and the ground be uncovered more quickly than it could be sown.

But as the fall of the river at Aswan during the first week in October was so slight, it was thought better to telegraph instructions to the Director of Girga Directorate to postpone the commencement of the discharge of the basins south of Sohag town to the 7th October, and of those to the north of Sohag until the 8th, and he was further instructed to conduct his discharge very slowly.

On the 8th October, as the Assiut gauge had risen, and the fall at Aswan was but slight, the Fifth Circle and Girga Directorate were telegraphed to stop further opening of escapes until the gauges again began to show a fall; and the Fourth Circle was also warned to be prepared for the postponement of the opening of Dalgawi escape. On the 12th the Fifth Circle was ordered to regulate its discharge so as to keep the reading on the Kasra Canal head gauge as near as possible to, but not exceeding, R.L. 66·30. Girga Directorate was to regulate its discharge by the Assiut Canal gauge, on which the reading was not to exceed R.L. 52·97. The opening of Dalgawi escape was postponed to the 15th October, the same date as in 1892.

It was thought at this time that it might be possible to keep the Roda (Cairo) gauge down to R.L. 20·25 metres (*i.e.* $24\frac{1}{2}$ cubits), and this is equivalent to R.L. 26·85 on the Wasta gauge. This level was therefore given to the Fourth Circle to work to; and if the reading was lower, advantage was to be taken of it to get rid of some of the Beni Suef basin water. But the opportunity did not occur before the final fall had commenced.

On the 16th, the Inspector Fifth Circle telegraphed that all canal heads were closed and escapes open, with the exception of Samhud basin, where the river was higher than the basin. This escape could not be opened till the 19th October, by which date the river had fallen to 41 centimetres below the basin level. After this its rate of discharge depended on the rate of fall of the river. On the 31st October the Inspector telegraphed that the discharge had been completed very satisfactorily, and that the following areas of sorghum and sugar had been protected throughout the flood from inundation :—

| | |
|---|---|
| Kena Province . . . . | 15,000 acres sugar-cane<br>80,000 „ sorghum |
| Aswan . . . . . | 16,000 „ „ |

The discharge of the basins in Girga Directorate was satisfactorily completed, and, with the exception of the case of Gharbia basin, all went smoothly, the levels maintained by the river preventing a too rapid discharge. The date on which the discharge was considered to be completed was not reported, but it was over in good time.

On reaching Cairo, after arranging the general lines on which the discharge was to be conducted, I discussed with Mr Foster the subject of the maximum level on the Cairo gauge which might be reached without producing more than ordinary difficulties in Lower Egypt, and we came to the conclusion that R.L. 20·45 metres ($24\frac{18}{24}$ cubits) was the most desirable level to maintain, as a higher level would produce serious difficulties, and a lower level could only be obtained on the condition that the basin water of Upper Egypt be passed off slowly and that the flood be proportionately prolonged in Lower Egypt in consequence. I therefore changed the reading on the Wasta gauge, to which the Fourth Circle might raise the river, from R.L. 26·85 to R.L. 26·95; but, on account of the high levels of Koshesha basin, the Inspector of Irrigation wisely waited to discharge the Beni Suef basins until the Koshesha basin level had fallen to R.L. 27·30. Before the basin had reached that level, the Wasta gauge-readings had fallen below R.L. 26·95.

It is, I think, the general opinion of Lower Egypt irrigation officers, that, if possible, the Cairo gauge-reading should not be allowed to exceed R.L. 20·45 metres (or $24\frac{18}{24}$ cubits); but this opinion is not universal, and Mr Willcocks considers it would be better to boldly let loose the Upper Egypt basin water, so as to get rid of it early, even though it produced levels exceeding 25 cubits. He would let it rise to R.L. 20·85 metres ($25\frac{1}{2}$ cubits), without hesitation, early in October. The long continuance of the flood at high levels produces much damage by infiltration behind the Nile banks, and the question is a choice of evils: extreme high levels producing danger of breaches, and prolonged high levels, though not extreme ones, producing much damage by filtration. The latter evil is certain to take place; but the former may, perhaps, be guarded against and avoided. Still, the damage, which would be far-reaching in the case of a breach, would be many times more considerable than the damage due to infiltration, which is limited to comparatively narrow strips of country inside the Nile banks.

On account of these considerations the R.L. of 20·45 metres was decided on as the level which it would be as well to reach but not to surpass, if the basin discharge could be so controlled as to produce this level. This level was, however,

surpassed for five days, but not by much, the maximum excess being eight centimetres.

Another question was raised as to the most suitable time for discharging the basins of the Fifth Circle and Girga Directorate, it being desirable to get their water past Cairo before the Middle Egypt water reaches Koshesha. It was suggested that the Upper Egypt basins were not discharged early enough, and that the discharge of the Fifth Circle might have commenced on the 25th September. This date, however, is too early in the interests of the Fifth Circle provinces, as sowing, after the retreat of the water, would in such a case have had to be begun before the favourable season. There would, however, not be much objection to beginning on the 1st October, though the 5th is preferable in the interest of the basin land itself. But no advantage to Lower Egypt would have been gained by so early a commencement as that suggested; for, by beginning the discharge on the 5th October and proceeding with it slowly at first—as was done in 1892 and 1894,—all the water that could have been got rid of by the basins was discharged before the 20th October; and the rate for the rest of the discharge depended on the rate of the fall of the river, as the tail escapes of basin chains could not discharge faster than they did for want of head. The result of commencing the discharge earlier would have been to have raised the levels at Cairo during the first ten days of October, to have lowered them for the second decade, and to have left them the same during the third decade. As the highest levels of the flood at Cairo occurred between the 23rd and the 29th October, there would then have been no advantage gained by advancing the date for commencing the discharge of the basins south of Assiut. The variant, which determines whether the Cairo gauge will rise high or not when the basin discharge of Middle Egypt is added to the river, is the rate at which the river discharge, where it enters Egypt, decreases. The effect of the Middle Egypt discharge, controlled as it was in 1892 and 1894, was not a variant, but, badly managed, might easily become a serious one. After a certain stage of the discharge, which is reached before the 20th October, the Upper Egypt basins also, since they fall with the river, become one with the river, and depend for their further emptying upon its levels as determined by the discharge passing the First Cataract.

From the above considerations I conclude that no relief to Lower Egypt would be experienced by making Upper Egypt commence its discharge earlier than the date which is most favourable for the sowing: namely, the 5th October.

Still, whatever improvements might have been introduced in the manner of handling the basins, the results of the flood of 1894 were very beneficial to Upper Egypt, due to the abundance of the water, and the fertilising matter carried by it. The inundation water was got rid of, in spite of the prolonged maintenance of high levels in the river, in time for the seed to be sown during the favourable season, and no complaints of delay in running off the water were received. The absence of such complaints, which were common in former years, is due to the attention that has been paid to the clearance of the drainage lines, which carry off the last of the basin water from the lowest lying lands.

The result was thus satisfactory in Upper Egypt, without prejudice to the interests of Lower Egypt, where there were no accidents, and little damage of any sort except that arising from the inevitable infiltration over a narrow strip within the river banks along both branches of the Nile. It was not until the flood subsided that it was possible to get rid of the greater part of this infiltration water."

62. **Selection from the Irrigation Report for 1899.**—Sir A. L. Webb wrote:—

"The Sohagia syphon, which has a length of 117·5 metres, and four barrels each 3·00 metres × 2·30 metres, carries the high-level Girgawia Canal under the Sohagia. On the morning of the 16th October, during the discharge of the basins, the level of the Girgawia Canal was R.L. 60·65 and of the Sohagia Canal R.L. 57·57 metres; it was then noticed that the water was bubbling up in the Sohagia Canal alongside the extreme edges of the syphon floor and, on closing off the regulator on the upstream side of the syphon well, it was found that the two outside barrels of the syphon had burst and that water was oozing out at the back of the abutments. Temporary measures were taken to close the outside barrels by means of wooden gates and the two central barrels were kept running, and the floor weighted with an earthen bank over the top.

A thorough examination of the syphon after pumping out the water has since revealed that the whole roof of the syphon over all four barrels was lifted, the abutments and piers being split across.

The weight of a cubic metre of the masonry has been found to be 1780 kilograms. Taking 1800 kilograms as the average weight of a cubic metre, we have upward pressure of water at the crown of the arch $= (60{\cdot}65 - 54{\cdot}46) \times 1000$ kilograms $= 6190$ kilograms per metre. Downward pressure (masonry and water) on roof $= (57{\cdot}57 - 56{\cdot}46) \times 1000 + (56{\cdot}46 - 54{\cdot}46) \times 1800 = 1110 + 3600 = 4710$ kilograms per metre. So that the syphon was burst by the excessive pressure of the water.

The whole of the masonry above the level of the cracks in the abutments and piers is being demolished, and will be rebuilt before the next flood.

Instructions regarding the gauges to be maintained on this syphon will be issued so as to prevent a similar accident happening in any future very low year."

63. **Selection from the Irrigation Report for 1907.**—Mr J. Langley writes:—

"The natural rise of the river affected the Aswan gauge on the 1st of August. The rise was very slow and unsatisfactory, the highest level reached being $13\frac{15}{24}$ cubits (R.L. 91·52 metres) on 3rd September. The flood was classed as a 'bad' Nile and gave considerable difficulty throughout.

Comparing with former low Niles, the following table shows that this year's mean supply was the worst on record, and that only in 1877 was the maximum level reached less that that of this year.

| Aswan Gauge in cubits. | 1877. | 1888. | 1899. | 1902. | 1904. | 1905. | 1907. |
|---|---|---|---|---|---|---|---|
| Maximum readings . . | $13\frac{10}{24}$ | $14\frac{16}{24}$ | $13\frac{22}{24}$ | 14 | $14\frac{11}{24}$ | $14\frac{8}{24}$ | $13\frac{15}{24}$ |
| Mean of 40 days ending September 24 . . | $12\frac{23}{24}$ | $13\frac{22}{24}$ | 13 | $12\frac{14}{24}$ | $13\frac{14}{24}$ | $13\frac{6}{24}$ | $12\frac{10}{24}$ |
| Mean of 55 days ending October 4 . . . | $12\frac{19}{24}$ | $13\frac{15}{24}$ | $12\frac{17}{24}$ | $12\frac{17}{24}$ | $13\frac{14}{24}$ | $12\frac{20}{24}$ | $12\frac{2}{24}$ |
| Mean of 72 days ending October 20 . . . | $12\frac{9}{24}$ | $12\frac{23}{24}$ | $12\frac{1}{24}$ | $12\frac{9}{24}$ | $13\frac{2}{24}$ | $12\frac{12}{24}$ | $11\frac{16}{24}$ |

During the past six years, or since the Assiut Barrage was built, regulation had to be resorted to in four years during flood.

On 7th August all the Barrage gates were lowered and the whole discharge passed over the top. On 8th August there was a head of 1·64 metres, which gradually decreased as the river rose, there being a head of 1·22 at the end of the month, and during September the head varied from 1·20 to 0·90 metres.

The Aswan basins suffered severely, there being no means by which they could be supplied.

In the Ramadi system, in addition to the area irrigated by means of temporary small banks, a considerable area was irrigated by lift.

In the Sahil Fashut system a considerable amount of work was done in making temporary banks by means of which large areas were flooded. A considerable area was irrigated by the Egyptian Irrigation Company's pumps at Naga Hammadi.

In the Bayadia system the cultivators supplemented the low supply by irrigating the millet crop from wells.

In Girga the escapes only drew water from the river for two days each. This deprived the lower ends of the basins of the usual red water supply.

Owing to the low level the Sohagia syphon was subject to a head from 2 to 2·30 metres for six weeks; this is a greater head than the syphon is supposed to be subjected to, but it stood well and helped to irrigate a large quantity of land which would otherwise have remained dry.

The Walidia syphon proved of great value: without it a very large area would have remained unirrigated. For a year like this it is too small to supply water for the whole area.

Owing to the steady improvements in the basin works, the area left unirrigated in the exceptionally low flood of 1907 was only 131,512 acres. The four previous typical low floods are given for comparison.

TABLE 176.—AREAS UNIRRIGATED IN LOW FLOODS.

| Province. | 1877. | 1888. | 1899. | 1902. | 1907. |
|---|---|---|---|---|---|
| Aswan | 62,000 | 5,418 | 19,401 | 13,767 | 22,353 |
| Kena | 257,883 | 113,938 | 79,254 | 69,526 | 81,724 |
| Girga | 267,114 | 78,303 | 44,649 | 12,001 | 9,340 |
| Assiut | 114,866 | 43,956 | 23,502 | 8,250 | 7,530 |
| Minia | 45,339 | 22,876 | 13,979 | 9,559 | 8,765 |
| Beni Suef | 6,790 | 4,619 | 8,137 | 3,022 | 1,800 |
| Total | 753,992 | 269,110 | 188,922 | 116,125 | 131,512 |
| Maximum reading (cubits) | $13\frac{10}{24}$ | $14\frac{16}{24}$ | $13\frac{22}{24}$ | 14 | $13\frac{15}{24}$ |
| Aswan gauge (R.L. metres) | 88·90 | 89·50 | 89·14 | 89·18 | 89·00 " |

64. **Selection from the Irrigation Report for 1908.**—Mr J. Langley writes:—

"All the breaches in the basin banks and canals might have been avoided if the Nile watchmen had worked up to the standard of a few years ago. Damage done by breaches, and neglect of protection by watchmen during the last flood, will cost the Government £10,000 to repair.

Power must be obtained for enforcing proper protection as existed in the past, or large sums of money must be annually placed at the disposal of the Irrigation Service for carrying out protective works by means of contractors to supply men and materials during flood."

## CHAPTER VI.

## *PERENNIAL IRRIGATION* (1).

65. Introduction.—66. Historical, Lower Egypt.—67. Historical, Upper Egypt.—68. Perennially Irrigated Lands in 1897.—69. Duty of Water.—70. Summer Discharges utilised and available.—71. Areas commanded and under Crop.

65. **Introduction.**—Perennial irrigation, as understood in Egypt to-day, is irrigation from canals which run the whole year round, as distinct from basin irrigation, which is performed by canals running only in flood. In CHAPTER IV. it was stated that in the basin tracts there are not only basins irrigated as basins, but that extensive areas on the Nile berms and in the basins have been enclosed by banks and protected from the flood waters of the Nile, and thus enabled to produce crops all the year round. Such tracts are, to all practical purposes, perennially irrigated, as are also considerable areas in the basins which are sown with millets in summer and irrigated from permanent and temporary wells in the basins themselves after the winter crops have been reaped. But as no special canals have been provided for supplying perennial irrigation to such tracts, they are not classed as perennially irrigated lands for which the State provides such irrigation. The area inside the basin tracts which enjoys perennial irrigation has been shown in the preceding chapter to be 240,330 acres out of a total basin area of 1,287,000 acres, or 19 per cent. This area is being steadily added to by an ever-increasing number of sakias and pumps on tube wells.

The area provided with perennial irrigation by the State covers 4,064,000 acres, thus subdivided :—

| | | Acres. | Acres. |
|---|---|---|---|
| UPPER EGYPT. | Ibrahimia Canal— | | |
| | *Ibrahimia proper* . . | 535,000 | 618,000 |
| | *Giza, left* . . . . | 83,000 | |
| | Fayum . . . . . . . . | | 304,000 |
| | Giza, right, on pumps . . . . | | 42,000 |
| | Upper Egypt . . . | | 964,000 |
| LOWER EGYPT. | West of Rosetta branch . . . | | 587,000 |
| | Delta proper . . . . . . | | 1,300,000 |
| | East of Damietta branch . . . | | 1,211,000 |
| | Suez . . . . . . . . | | 2,000 |
| | Lower Egypt . . . | | 3,100,000 |

66. **Historical, Lower Egypt.**—The following is from the second edition of this work, and gives a view of perennial irrigation in 1897:—

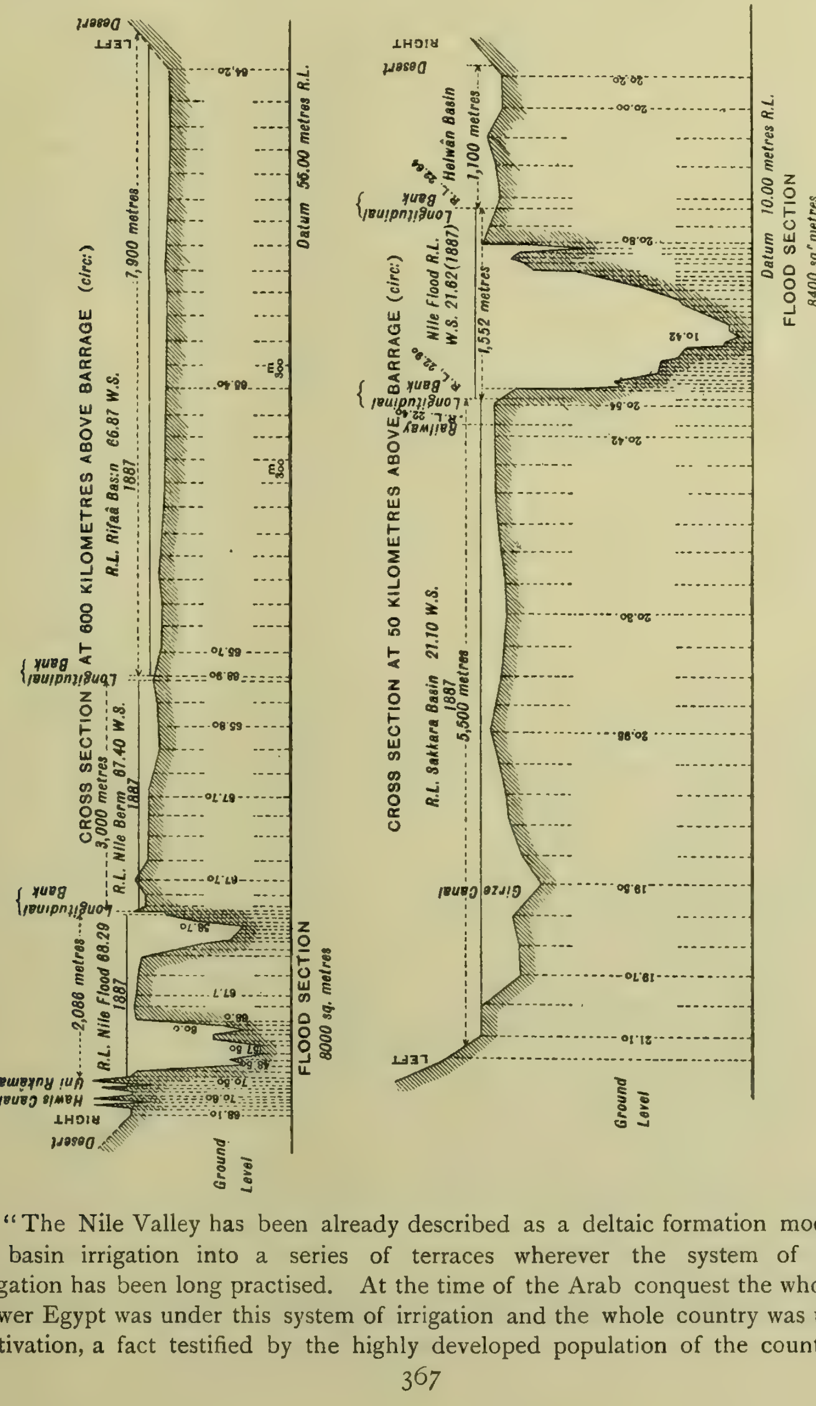



FIG. 26.—Cross Section of the Nile Valley in Egypt (1888).

"The Nile Valley has been already described as a deltaic formation modified by basin irrigation into a series of terraces wherever the system of basin irrigation has been long practised. At the time of the Arab conquest the whole of Lower Egypt was under this system of irrigation and the whole country was under cultivation, a fact testified by the highly developed population of the country as

recorded by historians, and by the countless remains of ancient towns and villages of considerable size, which now stand in the midst of vast desolations south of the northern lakes. Between A.D. 700 and A.D. 1800 the population had dwindled from 12,000,000 to 2,000,000 and irrigation had been abandoned over the greater part of the Delta. At the beginning of this century, basin irrigation was confined to an area upstream of a line roughly joining Delingat, Saft el Muluk, Damanhûr, Teh el Barud, Shibrakhet, Rahmania, Desuk, Sanhur il Medina, Nashart, Kallin, Simillay, Mehalla Kobra, Tira, Talkha, Mansura, Simbellawein, Safûr, Fakûs, Abûlakhdar, Bordein, and Bilbeis. Upstream of this line the country was more or less in terraces, while north of it the branches of the river and the natural canals flowed freely over the country and the regular deltaic formation was developed, cultivation being confined to the banks of the rivers and canals. Beginning at the head of the Delta the country is absolutely flat, and as one goes northwards towards the line of villages and towns just given, the valleys between the canals begin at first to be scarcely visible, while as one approaches the line the depressions are more evident, but not more evident than in the larger basins of Upper Egypt. North of the line the depressions are marked and become more so as one approaches the lakes. A cross section of this deltaic area would be somewhat as follows:—

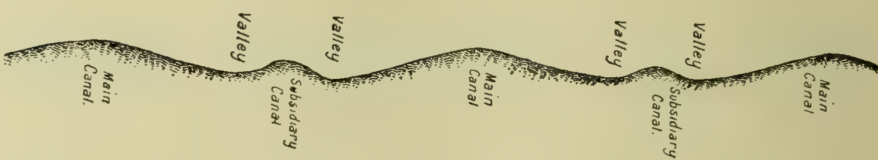



FIG. 27.

About the year 1820, Mohamed Ali Pasha changed the irrigation system of Lower Egypt by excavating a number of deep perennial canals capable of discharging the low-level summer supply of the Nile. The presence of this water in the canals allowed of the cultivation of cotton during the summer, and thus introduced cotton on a large scale into Egypt. Mohamed Ali strengthened the dykes of the Nile and of the canals, which dykes now assumed a fresh importance as they protected the country from inundation; he stereotyped this new system of irrigation, as he did everything else he took in hand. If the embankments of the basins had been maintained, the basins might have been filled periodically on the old system, and Lower Egypt to-day would have been enjoying all the advantages of cotton cultivation together with those of basin irrigation. This, however, was not to be; the old basins were neglected, the embankments ploughed up, and now that rich mud deposit which constituted the wealth of Lower Egypt for thousands of years can no longer be secured in full measure to renovate the land.

In all perennially irrigated tracts the year is divided into three seasons. The summer crops are sugar-cane, cotton, rice, millets, vegetables, and orchards, while clover is irrigated up to June. The summer is followed by the Nile or flood season, when the whole country is irrigated. The additional flood crops are millets, maize, and rice. The third season is winter, when the crops are clover, wheat, beans, barley, vetches, etc.

The summer season ends on the 1st of August, when the red water announcing the Nile flood first arrives; but as an early sown maize crop is more valuable than a

late sown one, every cultivator, who can, irrigates his land for maize in July. It is chiefly to prevent the people at the heads of the canals taking the whole of the water for their maize that the rotation system of irrigation has assumed such proportions. The summer is followed by the Nile or flood season. The flood crop of maize is the staple of food for the whole agricultural population. During the flood, in addition to maize, the cotton, rice, and sugar-cane crops are irrigated and matured, and the fallow land is put under water. The water for flood irrigation is obtained both from the perennial canals and from separate flood canals. The perennial canals are filled so as to command the country, while the flood canals are shallow ones, capable of taking in only the flood supply with their heads about $2\frac{1}{2}$ metres below the level of the country. The flood canals run through the flood months of August, September, October, and November. The third season is the winter, when the crops are wheat, beans, barley, clover, and vegetables.

As soon after the 30th July as water can be obtained the irrigation of land for maize sowing begins. The maize is sown up to the 10th September, but the late-sown crops are poor. The young plants are gradually thinned as they grow up, and provide green food for the cattle at this time of the year. For flood irrigation the earlier the Nile rises the better. The end of the flood is contemporaneous with the reaping of the maize crop, which is followed by a final heavy irrigation of the whole country, and the subsequent sowing of the wheat crop, after ploughing, and the clover generally without ploughing.

As soon as the flood irrigation is completed, the canals have the supplies at their heads very considerably reduced so that the whole country may be dried. This temporary reduction was first begun in 1887.

Of the existing canals a few are on new alignments, most follow the traces of the old channels, and are in consequence very winding and crooked. They, however, command the country well and intercept no drainage. They are in this respect vastly superior to the artificial canals, which were, as a rule, laid out very badly. Fig. 28 gives a contoured map of Lower Egypt, from which it will be seen that the longitudinal slope varies from $\frac{1}{10,800}$ near the apex to $\frac{1}{30,000}$, and even $\frac{1}{50,000}$, near the lakes. When Mohamed Ali began cotton cultivation, he deepened these natural channels, and dug some new ones sufficiently deep to take in the low-level summer water of the Nile. The yearly clearance of these canals entailed much labour on the country; and it was to obviate these difficulties that Mohamed Ali began the Barrages at the head of the Delta proper in 1835, and had it not been for the corvée, or forced labour, he would have finished them. The presence of the corvée enabled the Government to dig the canals deep at their heads and dispense with the Barrages; and afterwards, when difficulties arose owing to a partial failure of the Rosetta branch Barrage, it seemed easier to the Government to keep on calling out the corvée than to face the problem of the Barrages and definitely solve it. To these canals, deep only at their heads, Egyptian irrigation owed its difficulties. Canals meant to irrigate small tracts of land and needing during flood depths of from 2·5 to 3·0 metres of water, had depths of over 6 metres. They ran 1 metre deep in summer, and sufficed for the summer crop, which covered one-third the whole area commanded. During flood they irrigated the whole area, but had to run 6 metres deep in order to ensure flush irrigation along their entire lengths. The result was that regulators had to be built at intervals of 10 or 15 kilometres along the canals, and partially closed during flood to bring the water to


FIG. 28.—Plan of Lower Egypt (Contoured).
Contours 1 metre apart referred to mean sea. Scale 1/1,000,000.

the surface of the land. The checking of the velocity caused the Nile mud to settle in the beds of the canals in deposits of 2 metres and under, on hundreds of kilometres. This had to be removed yearly by the corvée at enormous cost. But this was only the beginning of evils. In spite of the closed regulators and numerous other contrivances, the canals were so disproportionately large at their heads during flood that they sent down into the lower lands further north, where the canals had not only not been increased but had actually decreased in size owing to neglect, such an excessive volume of water that all the canals, escapes, and drainage cuts were full to overflowing with flood water, and were, in consequence, unable to perform their proper functions. These low lands during flood were divided into a number of islands surrounded by water at a high level. The natural consequence was that salt efflorescence was greatly on the increase in the small area under cultivation; while 1,000,000 acres capable of reclamation were maintained in a state of swamp.

These evils were aggravated by the fact that the corvée, who cleared the heads of the canals, had so much silt clearance to do that they never had time to reach the tails of the canals and clear them of weeds and rushes. Thus the canals were kept very deep and capacious at their heads and allowed to dwindle away at their tails. The first result of raising the water level at the Barrages was to allow of the beds of the canals at their heads being raised 1 metre. These canals consequently carried less water in flood, and an immediate relief was felt in the low lands near their tails. Still the relief was insufficient, as the tails of the canals had been neglected for half a century. At this point the Irrigation Department made two mistakes. These mistakes were due to the fact that most of the Inspectors of Irrigation had received their training in Upper India, where the summer crop is the important crop of the year, and where the monsoon rains perform the irrigation in the rainy season which corresponds to the flood season here. So eager was the Department to give flush irrigation in summer that it overlooked the fact that canals which give flush irrigation in summer when they carry one-third the supply, must of necessity either carry an insufficient supply in flood or carry it at a level which will cause heavy saturation of the soil. The wholesale reductions of the sections of canals in their middle reaches which immediately followed have had disastrous effects on the subsoil water level of large areas, and have rendered many canals quite unfit to perform their duties in the earlier stages of the flood. The other mistake which the Department made was the conversion of the tail reaches of some of the canals, especially in Sharkia, into drains. It thus obtained cheap drains badly situated, but lost its flood escapes. Owing to the absence of these tail escapes, many canals have been turned into stagnant pools of water through eight months of the year.

The most important season of the year is the flood season, when the whole of the summer crop is being not only irrigated but manured with the muddy waters of the Nile, when the whole of the maize and rice crops are being irrigated, and when the fallow land is being washed and warped. With the exception, therefore, of the heads of the main canals and feeders, whose bed-levels must be regulated to suit the summer level of the Nile, the first requirement of every canal is that it should be of such a section and depth that at the beginning of the flood in August it could carry enough water at a moderate height above the level of the country to irrigate quickly the whole of the land commanded. Any canal which needs

rotations in August to enable it to carry water to its tail is inefficient. The next requirement of a canal is that the water should have a free and regular flow at a sufficient velocity throughout the flood, so as to be able to carry the muddy fertilising water of the flood to every field. Every canal, therefore, which is banked across and prevented from flowing freely and discharging into escapes or the lakes is faulty and harmful.

To prevent the water-logging of the soil and to keep the spring level well below the level of the country, it has been found convenient in certain localities to run the canals in alternate weeks, so that they act as drains in the intervening weeks, when they are practically closed. If the canals were of sufficient size it would be possible in this way to give flush irrigation on considerable reaches every alternate week without hurting the land.

When the water level of the canals throughout winter and summer is maintained below the surface of the ground, the soil is not salted, and is therefore capable of producing valuable maize crops, and the proprietors are not absolutely dependent on cotton. As, moreover, the water has to be raised throughout the summer for the cotton crop, the landed proprietors often prefer putting only one-third of their holdings under cotton, leaving two-thirds for the flood maize. Since cotton requires 1 cubic metre per second per 4000 acres, and only one-third of the land is under cotton, a supply of 1 cubic metre per second suffices for 12,000 acres of country. Great part of Lower Egypt was in this condition previous to 1884.

When, on the contrary, the water level of the canals throughout winter and summer is maintained above the surface of the ground the spring level is high, and all but the high land salted at the surface. The maize crop is sensible of any salt in the soil as its roots are shallow, while cotton with its deep roots is not nearly so sensitive. And as, in addition, water can be obtained cheaply by free flow throughout the summer for the cotton crop, the landed proprietors prefer putting half their land under cotton and half under maize. As half the land is under cotton, 1 cubic metre per second in summer suffices for 8000 acres. This heavier irrigation and rising spring level causes the low-lying parts to become too salted to produce maize at all, and then maize is confined to the highest lands, while rice and cotton are sown in rotation in the lower lands. One cubic metre of water per second suffices for 2200 acres of rice, and on such land, if one-third is under maize, one-third under cotton, and one-third under rice, 1 cubic metre of water in summer suffices for only 5000 acres of land.

We have thus seen that by heavy and high-level irrigation throughout the year, tracts which were eminently prosperous and contented with 1 cubic metre of water per second in summer for every 12,000 acres, now demand 1 cubic metre of water per second in summer for every 5000 acres. Tens of thousands of acres which were irrigated from wells in summer and from canals in flood, are now irrigated from canals all the year round, make heavy demands on the scanty summer supply of the Nile, and are not one-half (in many cases not one-fifth) as prosperous as they were before. Over hundreds of thousands of acres where drainage cuts were unheard of and perfectly unnecessary, drains to-day are a prime necessity. The proprietors of such lands, with their urgent appeals for more water in summer and more drains, can only be compared to the two daughters of the horse-leech. If, instead of listening to their appeals, canal officers were to boldly deepen and widen the canals and give the water a free flow down to the northern lakes,

they would save the men from themselves and large tracts of country from the fate which has overtaken the Wadi traversed by the high-level Ismailia Canal.

The demands for an ever-increasing supply of water and a perpetual extension of drainage cuts from these deteriorating tracts in the heart of the Delta must be put on a very different footing from the demands for more drains and more water from the tracts further north which were salted or marsh, and which to-day are being reclaimed and improved at great expense on the part of their proprietors. These tracts will be fully considered in CHAPTER VIII.

The following table gives the discharge of the canals through the twelve months of the year :—

TABLE 177.—LOWER EGYPT DISCHARGES IN AN AVERAGE YEAR PREVIOUS TO 1897.

| Month. | Discharge of the Nile at Cairo, cubic metres per second. | Discharge of the Delta Canals, cubic metres per second. | Percentage of Total taken by Canals. |
|---|---|---|---|
| January . . . . | 1590 | 300 | 19 |
| February . . . . | 1120 | 300 | 27 |
| March . . . . . | 800 | 300 | 37 |
| April . . . . . | 550 | 300 | 54 |
| May . . . . . | 430 | 350 | 80 |
| June . . . . . | 410 | 410 | 100 |
| July . . . . . | 1010 | 500 | 50 |
| August . . . . . | 5280 | 1000 | 19 |
| September . . . . | 7200 | 1200 | 17 |
| October . . . . | 6860 | 1200 | 18 |
| November . . . . | 3740 | 500 | 14 |
| December . . . . | 2260 | 300 | 13 |
| Year . . . . | 2610 | 550 | 21 |

It will be seen that in an average year the only month in which the whole supply of the Nile is utilised is June. The water in July is as valuable as gold, and cannot be utilised, as the Barrage cannot hold up more than 4 metres. To enable this July supply to be utilised, subsidiary weirs are being built below the existing works to allow of a head of 5 metres on the two works. This matter will be discussed in the chapter on Barrages. I may, however, state here that in my opinion it would have been better to have spent this money on building a Barrage or weir on the Damietta branch at Zifta or Samanud, and discharging the water into the lower reaches of the canals near where it would have been needed, instead of carrying it at a high level on the top of the existing summer supply, and so helping to still further raise the spring level in the heart of the Delta."

The following information has been obtained from Linant Pasha's *Memoirs* :—

"The excavation of the grand summer canals necessitated 110,000,000 cubic metres of earthwork, representing an expenditure of £3,300,000.

In a single year the Nile dykes were strengthened with 27,000,000 cubic

metres of earthwork. The yearly clearances of the deep summer canals in Lower Egypt before the construction of the Barrages used to be 13,300,000 cubic metres, representing an expenditure of £530,000 per annum. The measured discharges of the summer canals, before the Barrages were made, gave the amount of water entering the different provinces of Lower Egypt during an ordinary summer as follows:—

| | Cubic metres per second. |
|---|---|
| Behera Province | 11 |
| Menufia and Gharbia Provinces | 35 |
| Kaliubia, Sharkia, and Dakahlia | 18 |
| Delta | 64 " |

The Delta Barrages were completed in 1865; but, owing to accidents and difficulties, they were not continuously used till 1872, when the Rosetta branch Barrage was partially used and the Damietta branch Barrage not used at all. From this partial use, however, there resulted a great amelioration of supply, and the discharge entering the Delta canals was increased from 64 to 150 cubic metres per second. There were exceptional years like 1879 when both the Barrages were left open the whole year round and the discharge entering the canals never fell below 350 cubic metres per second, but a discharge of 150 cubic metres per second could ordinarily be counted on. In 1874 the discharge fell to 80 cubic metres per second, and in 1878 it fell to 110 cubic metres per second, but these were exceptionally low years. In 1884 both Barrages were used for the first time, and from then till 1891, when their repairs were completed, the water was held up to R.L. 13·00 on the gauge, and the discharge entering the canals rose to 280 cubic metres per second in an ordinary year, though there were years like 1889 when every drop in the Nile was utilised and yet the discharge fell to 220 cubic metres per second. Previous to 1884 the amount of silt clearance annually performed in Lower Egypt might have been put down as 16,000,000 cubic metres per year, costing the country £400,000. After 1884 the clearance might be put down as 8,500,000 cubic metres, costing the country £210,000 per annum. By 1891 the Barrages were repaired and rendered capable of holding up to R.L. 14·00 on the gauge. The cost of silt clearance did not decrease, as drainage cuts were maintained as well as canals; but the amount of water utilised rose to 370 cubic metres per second in an ordinary year, though in 1892 it fell to 330 cubic metres per second, as that was all the water in the Nile.

Since 1901 the Barrage has held up to R.L. 15·50 on its gauge, and since 1903 the water stored in the Aswan reservoir has been added to the summer supply of the Nile.

The following selections from old Irrigation Reports will give the early history of the working of the irrigation system of Lower Egypt.

The first is a selection from the Report of 1884, by Sir Colin Scott-Moncrieff:—

"In the Behêra Province more than any other the policy has been developed of supplying the canals by powerful steam pumps, one establishment having worked for many years at Atfeh where the Mahmudia Canal has its head in the Nile, the other worked for the first time in 1882 at Khatatba, about 100 kilometres further up the river. These pumps are the property of the Behêra Irrigation Society, and Government entered on an engagement to utilise them up to the year 1915, purchasing, up to the beginning of 1885, during the months of Low Nile up to three million cubic metres per diem, and after that up to five million cubic metres. When this contract was made there was of course no idea of bringing into use the Nile Barrage. We can only accept it as it exists, and try to make the best use of it.

During 1884 the Khatatba pumps worked from 1st May to 9th August, delivering on an average 12 cubic metres per second. The Atfeh pumps worked from 17th March to 15th August, delivering 16 cubic metres per second.

The rise of the Nile was unusually late last year—or these pumps would have ceased earlier. Government paid to the Society £27,426 for this water supply."

In the Report for 1885, Sir Colin Scott-Moncrieff writes as follows:—

"The two great canals of the Sharkia Province are the Sharkawia and the Bahr-Moes. The former rising above the Barrage has its supply thus ensured to it. The head of the Bahr-Moes is below Benha and therefore uninfluenced by the Barrage, and it was chiefly to keep it supplied that the temporary dam across the Nile was erected.

The idea of throwing such a bar across the Nile was due to Mr Willcocks, and it was an idea received in the country with great doubt, not to say alarm. It was confidently asserted that we should not be able to remove it before the Nile rose, and an inundation was predicted. It was begun early in April and held up at the maximum 1·07 metres.

It was 430 metres long, consisted of 16,000 cubic metres of stone and burnt brick, and cost £2520. By the middle of July it had been removed and formed not the slightest impediment to the river during flood. The effect of this dam was to give abundance of water to the district N.E. of Zagazig, where previously at this season there had been drought.

For the first time this year the Bahr-Moes was cleared by dredgers instead of by corvée labour. The dredgers were not well adapted for their work, which was therefore costly and not very good, but the corvée was spared labour, and Zagazig enjoyed an unbroken water supply throughout the whole year.

Our efforts to divert the water from the river into the canals by the use of the Barrage had an effect we did not anticipate. The water at Khatatba on the Rosetta branch fell so low that the pumps could not work; and as their level had been fixed by Government, it was necessary to throw a light dam across the river to hold up the water surface half a metre. As the low water had stopped all navigation, stones could not be brought down for use on this dam. It was made therefore by running out earthen banks from both sides, leaving a space of 70 metres in the middle, which was closed by sand bags. The cost was £1426, upwards of 16,500 bags of earth were used, and the desired object was effected.

A more serious difficulty arose from the influx of salt water, which unless controlled would have reached as far as the Atfeh pumps which supply the Mahmudia Canal and the city of Alexandria. This difficulty showed itself early in April, and to prevent it Mr Foster threw a dam over the river at Mehallet el Amir. It was composed of earth, and was carried out in water from 2 to 5 metres deep with the help of about 400 piles for a distance of 180 metres on the one side and 250 metres on the other, leaving an opening of about 70 metres in the centre. This dam cost £7536. It was maintained with much difficulty, the north wind blowing heavy waves against it. Usually the water flowed outwards through the contracted opening, but on several occasions while there was a distinct under current outwards of fresh water Mr Foster found a surface current of salt water inwards, and for 204 hours altogether the Atfeh pumps were unable to work.

As in Gharbia there was serious injury inflicted in Behêra also on those who irrigated downstream of the Mehallet el Amir dam. Altogether 5042 acres of rice were reported as injured, and a remission of £3979 taxation was made.

Another serious consideration was the supply of drinking water to the old town of Rosetta. Like other Egyptian towns, Rosetta possesses a number of fine cisterns under the houses, which are intended to be filled during high Nile. But they had been neglected, and when the fresh water ceased to come down the river it was necessary to take prompt measures. First, a daily train of tank carriages was organised from Alexandria, and afterwards a regular boat service was established on the river, barges being filled with fresh water daily at the dam and towed by a steam tug down to Rosetta. This water service answered well and cost altogether £539. While all this was in operation we availed ourselves of the services of Mr Cornish, C.M.G., the well-known Director of the Alexandria water works, who most kindly volunteered to superintend an experimental boring at Rosetta for an artesian well. The boring was carried to a depth of 153 feet, but without success, and as the cost was already £252, it was thought better to go no further.

I have thus thought it right to enter fully into the injury effected towards the two mouths of the Nile by the abstraction of the water. I have shown that the river was exceptionally low, and that our machinery for distributing the water was defective. With it all 8967 acres of rice land were reported to have suffered. Even assuming that this was below the mark, I believe I can state fearlessly that at least ten times the area derived great benefit, and that a very large tract, especially in Sharkia, received water during summer which had never received it before.

As the Nile rose in August an experiment was made. It had been customary to close the Rayah Behêra entirely at this season and admit water into Behêra by the head of the Khatatba Canal. In 1885 the Rayah Behêra ran continuously throughout the flood. The result was good, in so far that early muddy water was given, to the great benefit of the maize crop; but the force of the current cutting between the sandy banks of the canal about 20 kilometres from the head tended to make it wider and shallower to an extent that has caused us much trouble since. No effort should be spared to make the Rayah Behêra the one source of supply for the province, but it will require considerable outlay and trouble before the upper portion is brought into a satisfactory condition."

The next selection is from Sir Colin's Report for 1886:—

"The system of throwing temporary dams across the river which had been

successfully tried in 1885 was continued and extended in 1886. On the Rosetta branch a dam was placed, as in 1885, downstream of the Khatatba pumps, commenced at the end of March and finished in the middle of April at the cost of £2609. The object of this was to hold up the water surface sufficiently to allow of the Khatatba pumps working.

The Mehallet el Amir dam was renewed a few miles above Rosetta to keep in the fresh water of the river, and still more to exclude the salt water of the sea which would otherwise have been pumped into the Mahmudia Canal. In 1885 this dam cost £7556. In 1886 it cost as much as £11,022, a very heavy charge. In 1885 the dam was not closed right across the river, but an opening was left in the middle. In 1886 the river was entirely barred, and a carriage might have driven across it. On one side the water was perfectly fresh, on the other quite salt. This dam was begun on the 17th February, an earthen bank being thrown out a distance of 332 metres on one side and 304 metres on the other, the average depth of water being about 4 metres. This left an opening of 70 metres in the middle, across which a rough stone and brick weir was thrown. On 12th May the dam was closed. The rising flood carried away the dam in July, but the brick portion remained and would have formed a danger to the navigation had not a boat been moored at each end to mark its position, with lights at night. Mr Foster hopes to make the dam much cheaper in 1887, but I fear it will be impossible to dispense with it altogether until we have so rearranged the irrigation system of Behêra as to render us independent of the pumps at Atfeh. When the canals of Behêra can be fed entirely from the Rayah Behêra and Khatatba it will be no longer necessary to keep out the salt water.

On the Damietta branch the dam built last year below the head of the Sahel Canal and Bahr-Moes was renewed. Its total length was 200 metres. In 1885 16,000 cubic metres of stone and brick were used in this work. In 1886 it only required an addition of 3706 cubic metres, which cost £581. It was used this year to hold up 1·05 metres of water, which was enough for the supply of these two canals.

Mr Garstin constructed another very successful dam over the river below the head of the Mansuria and Om Salama Canals. This proved of the greatest help to the irrigation of Dakahlia and successfully held up ·63 metre of water. It was 156 metres long, connected in the right flank to the high river's edge by an earthen insubmersible embankment 137 metres long. The dam consisted of a rough stone platform 18 metres wide and about 2·8 metres high above bed level. The top was 4 metres above mean sea-level. On this was built a crest wall 1·41 metres high. It was finished by 17th May, contained 6387 metres of stone and brick, and cost £3945. It was easily removed by the end of July.

One other dam or *sudd* was placed across the river 5 kilometres downstream of Damietta, in order to keep out the salt water and to enable the low lands between the city and the sea to be irrigated by a new canal (termed the Ezbet el Burg Canal).

This dam was made of sand and earth, faced on the northern side with bricks to protect it from the action of the waves. It was laid in water about 4 metres deep for a length of 400 metres, which was found enough, for it left an opening sufficiently contracted to ensure a constant flow outwards. It cost £2585."

The following selections are from Sir Colin Scott-Moncrieff's Report for 1888:—

"The 'sudds' or closure embankments across the tails of the canals in Gharbia to prevent the water running to waste in the sea were made and removed as follows—

| | | | | | |
|---|---|---|---|---|---|
| On the Bahr | Malha: | made | 1st January, | removed | 3rd September |
| " | Tira | " | 15th February, | " | 31st August |
| " | Shibin | " | 15th January, | " | 31st " |
| " | Nashart | " | 25th March, | " | 18th " |

The late date of the removals of these 'sudds' was due to the deficient Nile flood.

The summer was a hot dry one, and it was with great difficulty that Mr Willcocks managed to keep the great cotton crop alive. On the 15th May he commenced the rotation of irrigation by closing the canals for seven days out of twenty-one. From the 20th June he could only keep them running for seven days out of fourteen. From the 5th July to the 11th August the canals were closed for fourteen days out of twenty-one. This was fatal to the rice crops, the interest of which it was necessary to sacrifice in order to keep the cotton crop alive.

The most important thing to be done for the irrigation of Behêra is the restoration of the Rayah Behêra, or canal taken from above the Barrage, to enable it to carry water sufficient for the irrigation of the province, and to render it independent of the costly pumping at Atfeh and Khatatba. There is no other canal in Egypt so unsatisfactory and so discouraging. Large sums have been spent on it year by year, and yet it is until now practically valueless. It would have probably been easier and cheaper to have made an entirely new canal than to have gone on as we have done, trying to restore to usefulness a very bad canal.

In 1885 and 1886 the unfortunate experiment was made of running this canal during Nile flood, in the hope that a scour would be produced and the bed deepened. Exactly the contrary took place. The sandy banks fell in, and the bed widened and was choked by a deposit of sand. Some of this was cleared away early in 1887, but the great flood of that year burst through its banks and again a great sand deposit was formed. All the dredging done since then has failed to bring the canal to a proper level, and the irrigation of Behêra is really effected by the pumping stations.

But in spite of all discouragement the Rayah Behêra is being put into order. I am hopeful that after 1st May 1890 we shall be able to dispense with the Khatatba pumps, and in 1891 that Behêra will derive its irrigation from this canal and no further pumping will be required.

The pumps worked as follows throughout the year 1888:—

| | Commenced Pumping. | Finished Pumping. | Days Working. | Mean Discharge per second. |
|---|---|---|---|---|
| | | | | cubic metres |
| Atfeh . . | November 25, 1887 | August 25, 1888 | 276 | 20 |
| Khatatba . | February 8, 1888 | 12, " | 185 | 27 |
| Total discharge per second . . . . . . | | | | 47 |

The amount paid to the Behêra Irrigation Society for this water was £61,255. It would have been well to have begun the Khatatba pumps at an earlier date. As it was, during the cotton crop and until the Nile rose the pumps were daily supplying 61 cubic metres per second, a larger volume than was ever furnished before.

The dredging ceased and the Rayah Behêra was opened on 1st June, but it only added 6 cubic metres to the discharge. The system of giving irrigation by rotation on different canals was practised again this year in Behêra, and met with the same unreasoning opposition. I trust now, however, the agricultural classes have learned that this system is not one of choice but of absolute necessity if the present area of irrigation is to be maintained in summer."

The next selection is from Colonel Ross's Report for 1889, one of the worst summer supplies of this century.

"The following discharges were taken by Mr Reid, on 16th May, at the Barrage, and those of 7th July were deduced from them.

| Date. | Rosetta Branch. | | Damietta Branch. | | Rayah Menufia. | | Total Discharge, cubic metres per second. |
|---|---|---|---|---|---|---|---|
| | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. | |
| May 16 . | 10·00 | 32 | 11·00 | 70 | 12·90 | 92 | 194 |
| July 7 . | 9·60 | 24 | 10·70 | 58 | 12·65 | 83 | 165 |

The discharges of 7th July were practically the minimum of the year. If we add 35 cubic metres for the supply of the canals taking off between Cairo and the Barrage, we have a minimum of 200 cubic metres per second passing Cairo.

If we compare the very low summer Nile of 1878, which closely resembles the year 1889, we find the cotton exported from Alexandria:—

1878, 1,680,595 kantars or cwt.

1889, 3,200,000, of which perhaps 200,000 kantars were from Upper Egypt.

This magnificent increase has been obtained by utilising the whole amount of water in the river by holding it up at the Barrage and the 'sudds' (earth and stone dams) across the river. The great personal efforts of the engineering staff aided by the civil authorities also contributed to this magnificent result. It must be borne in mind also that the yield of 1878 per acre was greater than that of 1889, owing to the existence of the cotton worm in greatly increased numbers in 1889. The area of 1889 is probably four times that of 1878.

In the First Circle (the country east of the Damietta branch) the scarcity of water was decidedly obviated by the very skilful maintenance by Mr Garstin of the dams and bars of stone and earth across the Nile. The Damietta branch was ponded up by the dam at Mit Ghamr to such an extent that the river to the north was so low at Mansura that children could walk across it. The dams of Benha and Mit Ghamr have held up as follows as maximum heads:—

| | 1888. | 1889. |
|---|---|---|
| Benha dam . . . . . . . . . . | 1·50 | 2·25 |
| Mit Ghamr dam . . . . . . . . | 1·43 | 3·20 |

These enormous maximum heads were maintained for nearly all July.

The Damietta dam was fully closed this year, but somewhat too late to prevent a rush of salt water for about 50 kilometres. The cost and details of these dams were as follows:—

| Name. | Stone. | Earth-work. | Cotton Sacks. | Sand Bags. | Cotton Sheeting. | Rope Bags. | ... | Cost. |
|---|---|---|---|---|---|---|---|---|
| | cubic metres. | cubic metres. | No. | No. | No. | No. | cubic metres. | £ |
| Benha | 8991 | 1,113 | 50 | ... | ... | 20 | 3830 | 6690 |
| Mit Ghamr | 7796 | 17,529 | 2712 | 4878 | 2355 | ... | ... | 6493 |
| Damietta | *À forfait* and dredging | | | | | | | 4700 |

Full rotations were put in force as follows:—

| Name. | Date of First Stopping Engines. | Date of First Stopping Canals. |
|---|---|---|
| Kaliubia | June 21 | March 26 |
| Sharkia | July 6 | July 2 |
| Dakahlia | June 17 | July 1 |

In the latter part of the time of scarcity very severe rotations had to be put on. Mr Willcocks notes as follows for the Second Circle.

Where the rotation system did not fail and one irrigation per twenty days was secured, the cotton gave magnificent yields. The yield was better than what it was on the Nile where there was no limit to the irrigation. Crops irrigated once in thirty days suffered slightly, irrigated once in forty days suffered appreciably, and irrigated once in sixty days preserved their foliage, but gave no yield.

Long canals such as the Sahel and the Khadrawia were divided into reaches of some 35 or 40 kilometres each and fed from new feeders. If this were possible everywhere, there would be no necessity to stop engines except on the main canals.

The Kâsid with its great length and innumerable branches had ten days' closure of its minor canal heads and stoppage of its engines alternately. This was fairly successful. The minor canals were all deepened and widened to allow of this. The same was done on the Gafaria and Bahr Shebin minor canals. The Bahr Saidi was fed through the Om Yusuf drain. By this means it got every cubic metre sent down to it, as there are no machines in the drain, and 25 difficult kilometres were got over.

The three canals where irrigation failed were the Nenaïa, Sirsawia, and the Bahr Sef. These canals are between 90 and 50 kilometres long each, and traverse the heart of the small-holdings tracts, where water-wheels abound. Stoppage of engines without stoppage of water-wheels has been proved to be of no avail; and in 1890 it has been proposed to stop every kind of irrigation as well as the engines. The sheikhs have unanimously given their consent on condition that whenever the engines are stopped for ten days, the wheels, etc., will be stopped for six and run for fourteen days. If the Governor of the province can enforce this rotation, irrigation will be easy.

In the Third Circle, the water pumped from Khatatba and Atfeh was distributed most carefully by rotation commencing from the 17th of February. In this circle the people have, since the necessity of sending application for water-wheels was abolished, built large numbers of these wheels, and although this is a gratifying sign of the existence of capital, it has somewhat thrown the canal system out of gear, more especially on the Rosetta Canal, and the result has been that the small quantity of water available for the Rosetta Canal frequently failed to reach Rosetta. Up to the present, native opinion has been very averse to imposing rotations on water-wheels; but as they have multiplied so much it will be necessary in the future to impose it, more especially on canals where there are large towns dependent on the supply reaching the end of the canal.

The Rosetta dam was made this year for £9170. The cost of the dam since 1886 has been—

| 1886. | 1887. | 1888. | 1889. |
|---|---|---|---|
| £11,384 | £10,649 | £10,840 | £9170 |

Mr Foster has paid great attention to cutting the dam on the rising Nile so as to prevent the scouring of deep holes, and the result is that the *à forfait* price in 1890 is only £8000.

The Khatatba dam, principally made of stone, is necessary to maintain the river to contract level at the Khatatba pumps. The head on it is not great, and it is always thoroughly in hand. The comparative cost is this:—

| 1885. | 1886. | 1887. | 1888. | 1889. |
|---|---|---|---|---|
| £1426 | £2608 | £2329 | £818 | £1656 |

The amount of water passing through the Rosetta branch in the low Nile of June and July was 18 cubic metres per second, and the amount drawn out of it by the Khatatba and Atfeh pumps was 41 cubic metres. Hence the balance, or 23 cubic metres per second, was drawn from the filtration water of the river. The filtration water is salter than the Nile, and is therefore not so fit for use. The Atfeh pumps so exhausted the supply of fresh water that the Nile at Atfeh (60 kilometres from the Rosetta dam) was a still-water pond held above the sea-level by the dam, and with a film of fresh water on it only 40 centimetres deep, floating on the top of a deep layer of salt water, so salt as to be quite unfit for irrigation and drinking purposes. Had the low supply lasted one week longer, we should have been compelled to deprive the Central and Eastern Provinces of a portion of their water to sweeten this great pond from which Alexandria draws its drinking water, as it was falling at the rate of 2 centimetres a day, and the water-wheels of the Atfeh pumps could not have worked with a further fall of 30 centimetres."

It will be seen from a perusal of the above that the minimum discharge of the Nile was 200 cubic metres per second, and that the infiltration water utilised on the Rosetta branch was 23 cubic metres per second; as about the same quantity was utilised on the Damietta branch, the total discharge utilised was 246 cubic metres per second, of which 82 per cent. was Nile water and 18 per cent. was infiltration water.

Colonel Ross writes in 1890:—

"The First Circle was completely revolutionised by the opening of the Rayah Tewfiki, the new canal taking off from above the Barrage and feeding the Bahr-

Mues, Sâhil Canal, Um-Salama Canal, Mansûria Canal, and the Sharkâwî-Fâraskûr. This fine canal, designed and completed by Colonel J. H. Western, C.M.G., out of the million loan, now supplies all the northern part of the province of Sharkia and all the province of Dakahlia."

In the report for 1891 Mr Foster writes as follows on the excellent work done on the Behêra feeder canal or Rayah Behêra:—

"The restoration of the Râyah Behêra may be considered to have commenced in the beginning of 1888. It remains now to show what has been done since, and the results obtained. It was decided that the canal should be given a section of bed width of 20 metres; level of bed at head sluice R.L. 10·00; slope in bed 65 millimetres per kilometre $\left(\frac{1}{15,384}\right)$, and it was with this end in view that all operations were carried on. I should say also, that in disposing of silt, sufficient space has been given to permit of the bed width being increased to 26 metres and the slope to 75 millimetres per kilometre.

In 1888 the quantity removed by machine and hand labour was 390,729 cubic metres. Work was suspended during flood and commenced in October of that year. From this time until May 1891, dredging was continued throughout the year. Machines were imprisoned during flood between dams, where they worked in still water. These dams were cut in 1889 on 1st June, in 1890 on 1st April, and again on 12th December for the supply of water for irrigation. (I may here note in passing that the Khatatba pump ceased to work on the 10th April 1890, and those at Atfeh on the 10th August of the same year.) By the end of May 1891 the section towards which we had been working had been secured with the exception of a few kilometres (14 to 20) where erosion of banks caused by the employment of large dredgers in flowing water had caused the bed to rise. The clearing of this lump was postponed until after flood, and it was nearly removed by the end of the year.

| | Cubic metres. |
|---|---|
| The total quantity of cubes dredged from October 1888 to May 1891 was 3,162,060 cubic metres, which, added to those worked early in 1888, makes a total of . | 3,552,729 |
| Add dredging of the unfinished lump on kilometres 14 to 20, being done in 1892 . . . . . . | 200,000 |
| Grand total . . | 3,752,729 |

Besides the above dredging, the removal of stone dams at the head and at kilometre 8 was continued, the latter having been completed and the former nearly so.

The centre line was worked from the railway which is carried on the left bank. In this way, lines have been made straight and curves true. Where the canal was too wide (in some places it was as much as 70 metres) dredged stuff was deposited in such a manner as to reduce the section. Where it was the required width or less, all out-turn was discharged outside the bank.

With the exception of a short length of 100 metres, all sand has been put on the right or eastern bank, prevailing winds being from the west. On the first 9 kilometres, silt has been carried out into the Nile or discharged into slurry pits on either bank.

Finding cheap materials for spur-making, such as old timber and sacks, to be a failure, sanction was given for the manufacture of bricks for the purpose. Stone would have been used, but the depth of water was insufficient to float the smallest Nile boat.

Sufficient clay had been deposited during the flood of 1885 and 1886 to supply what was required for brick-making. Bricks made were 40 × 20 × 10 centimetres, and were built into spurs for 45 piastres per cubic metre. Transport was effected by rafts constructed by the contractor at his own expense. A very large number of spurs (upwards of 200) were built in 1888 between kilometres 11 and 32. In 1889 and 1890 a few more were made, partly of stone and partly from brick dug out of buried portions of old spurs, and the old ones repaired. In 1891 another lot was made between kilometres 32 and 39, and a number of smaller ones wherever there were any signs of erosion. On the straight, spurs are placed opposite each other every 200 metres. In certain places they are closer. On flat curves they are placed at every 100 metres on the outside, and every 200 on the inside bank. On sharp curves at every 50 metres on outside and from 100 to 200 metres apart on the inside. Small spurs to put a stop to local erosion are placed from 30 to 50 metres apart. The total number of spurs existing is 475 on kilometres 9 to 40, or an average of 15 per kilometre.

It has been stated above that the plantation of grass and willows was tried in 1886 and 1887, and it has been carried on since without intermission. The left-hand bank was practically completed by the end of 1889. On the right, plantation has followed dredging, and at the present time, though not as thick as on the left, grass covers the bank from below summer level to a considerable height above flood level. During 1889 and subsequent floods, grass has been planted in the western district along the foot of the hills, around hillocks, and alongside the railway. A staff of men varying from 20 to 50 according to the season have been thus employed. In addition to grass, a number of acacia and other trees have been planted, and are, for the most part, doing well. The tufts of grass, 'Buss Hagna,' mentioned as found on kilometre 26, are the parents of nearly all that now exists. Other kinds have been tried, the 'Hagna' with success, but 'Buss Baladi' not so. 'Buss Hagna,' which is different to 'Hagna,' will only grow in loose sand. Even a small admixture of clay kills it. Hagna grows very thick and has a multitude of roots. A little trouble has been given by Burdi grass, which grows in deep water. This is the grass which chokes drains. All these grasses seed once a year. The fact that grass is growing in the desert where none has been planted, shows that the seed is blown about by the wind and germinates.

Prior to 1888, 11 kilometres, and in 1888 11 kilometres of screens were erected, 22 metres from the railway on the desert side. This distance was fixed by the Railway Administration. In 1889 spaces omitted the year before were filled up and a second row erected in some of the worst places. By the end of this year screens extended in a continuous line from kilometre 10 to 36. In 1890 and 1891 second rows were added in a few bad places. In these two years the Railway Administration supplied the material required for screens free of cost and the Irrigation Service erected them. The Railway Administration recognised the good they were doing to the railway itself. Screens made up to the end of 1889 were 1½ metres high, composed of cotton stalks kept in position by upright timbers

and horizontal laths. The railway supplied 'tarfa,'* which is more enduring than cotton stalks and does not require timber supports. It is stuck into the ground at an angle and roughly plaited together, the completed screen being about 1 metre. It is needless to say it is much the cheaper of the two kinds.

A statement at the end of this Report gives details of expenditure.

The total sums spent have been as follows :—

TABLE 178.—RAYAH BEHÊRA EXPENDITURE.

| Detail. | Prior to 1888. | 1888 to 1892. | Total. |
|---|---|---|---|
| | £ | £ | £ |
| Dredging, including removing stone dams | 19,829 | 157,772 | 177,601 |
| Spurs | 14,238 | 8,548 | 22,786 |
| Plantation | 581 | 1,674 | 2,255 |
| Sand screens | 753 | 773 | 1,526 |
| Flooding | 3,389 | 7,691 | 11,080 |
| Contingencies | 451 | 586 | 1,037 |
| Totals . . £ | 39,241 | 177,044 | 216,285 |

The Rayah Behêra will require the most careful watching for some years. Wherever erosion of banks appears a spur must be erected. Grass must be renewed wherever necessary. Dredging must always be done over the bank, that is to say, that dredged stuff must be discharged outside the bank, and always on the right or east side from kilometres 9 to 41.

The Rayah Behêra must not be used during high Nile before regulators have been built."

The following selection is from Major (now Sir) Hanbury Brown's Report for 1894 :—

"As, during the year 1894, the large pumping stations at Khatatba and Atfeh became the property of Government by an arrangement concluded with the Behera Irrigation Company, it will be convenient to record their history in this Report under the head of Summer Irrigation, to provide for which they were set up.

According to Linant, Alexandria in 1810 was a purely Arab town; it developed in Mohamed Ali's reign. Communication between Alexandria and Cairo was carried on, up to 1819, by sea from Alexandria to Rosetta or Damietta, or by land to Rosetta, and thence by river to Cairo.

At this time Alexandria obtained its water supply from cisterns filled by the winter rains or by flood water from the river arriving by way of the old canal of Alexandria and by percolation. This old canal of Alexandria had its mouth on the Rosetta branch of the Nile at Rahmania, and on its way to Alexandria passed by Zawyet el Ghazal. Mohamed Ali replaced this canal by the Mahmudia with its Nile intake at Atfeh and its junction with the old canal at Zawyet el Ghazal. The Mahmudia was designed to be navigable, but long after its excavation transhipments had to take place at Atfeh, until in 1842 a lock was constructed there.

* Tamarisk.

During flood and early winter the Mahmudia Canal derived its supply from the Khatatba Canal, which tails into it at 15 kilometres from the river at Atfeh, at which place also the flood waters were admitted to the canal. Later in the year, on the Khatatba Canal ceasing to flow into the Mahmudia, the supply was kept up for some time longer by means of water stored in an artificial reservoir of feeble capacity, known as the 'Khazzan,' and admitted to the canal by the Zargan regulator. This reservoir, which was filled during flood, covered about 10,000 acres on the south sides of the first 8 kilometres of the Mahmudia Canal, the left bank of which formed the retaining bank of the reservoir. The depth of water in the reservoir was not enough to provide a sufficiently prolonged supply, and thus the crops depending on it suffered and the town of Alexandria had to fall back on its cisterns, of which hundreds still exist, though no longer used. After the Atfeh pumps were set up the reservoir ceased to be maintained as such, and its bed was brought under cultivation.

As the Mahmudia supply under these conditions was unsatisfactory, Linant Pasha in 1849 proposed the creation of a pumping station at Atfeh, which project was prepared by Mougel Bey and d'Arnaud Bey, and carried out by the latter. But, with this pumping station, Alexandria, as Linant records, had not enough water in 1869 and 1870, and moreover, in spite of the deficiency, an engine was erected on the canal to supply Ramleh: whence he concluded that the pumping station at Atfeh must be enlarged.

The first pump set up at Atfeh consisted of two large beam engines of English make driving four small turbines, the discharge from which was probably not more than 5·5 cubic metres per second. Some years later the pumps were changed for others of modern type, the engines remaining as before. About 1870 this pumping station was enlarged and made capable of lifting 10 cubic metres per second, but the supply was not constant, until the Behera Irrigation Company in 1881 took the contract for working the pumps.

During the period from 1847 to 1870 the Barrage had been built, had failed, and been condemned as a useless structure, and it was therefore determined to supply the Delta with summer water by means of enormous pumping stations. The Behera Canal also had failed, and the influential landowners of Behera having made their voices heard in the public offices in Cairo, it was decided to apply the system first to Behera, by erecting a new pumping station at Khatatba and enlarging the existing one at Atfeh. The contract for carrying this out was given to the Behera Irrigation Company in May 1880. This company undertook to make the new and to enlarge the existing pumping station, and to deliver 17 cubic metres per second from each station. In January 1883 the quantities to be delivered were increased to 29 cubic metres per second at Khatatba and 23 at Atfeh. The lift at Khatatba was about 2·65 metres as a maximum and 2·00 metres as a mean; and at Atfeh 2 metres as a maximum and 1·20 as a mean.

Mr Foster gives the following description of these pumping stations:—

'From February 1881 the Atfeh pumps were to give 17 cubic metres per second. However, the Atfeh pumps were worked to the utmost of their capacity, but the 17 cubic metres were not produced. The company then decided to employ the Sagobien wheel. When I first saw the Atfeh station in May 1894, four of these wheels were working on the two beam engines and doing very good work, and delivering almost as much water as required. In January 1883 Government made

another convention by which the company undertook to supply 23 cubic metres per second. By the season of 1886 four more wheels on the same design were added, worked by two inverted marine engines. The whole eight wheels have lifted as much as 35 cubic metres per second. They are the most efficient water lift for low lifts in existence. By carefully made experiments they showed 95 per cent. effective duty. The Atfeh pumps never gave any trouble after 1886.

'The increase in the quantity of water supplied to the Mahmudia by the Atfeh pumps has been approximately as follows:—

| | Cubic metres per second. |
|---|---|
| '1858 to (1868?) | 6 |
| 1869 (?) to 1881 | 10 |
| 1882 to 1885 | 17 |
| 1886 until pumps suppressed | 23 to 35 |

'The cost of lifting water before 1881 is not known; probably it was enormous. Since that date, however, all has been done by contract at the following rates:—

'By the contract of 1880, £24 per million metres cube. This was increased by the convention of 1883 to £26 until 1885, and from 1886 to £28 per million metres cube.

'Although the Atfeh pumps worked for a few days in 1892, 1893, and 1894 on the rising flood, they may be considered to have ceased to function when they were stopped in August 1890.

'At Khatatba the Behera Irrigation Company made the unfortunate mistake of trying to turn Archimedean screws on one single shaft. To give the full supply required, ten screws had to be used. Three inverted marine engines worked on the one shaft, one or more working according to the number of screws in motion. This experiment proved a great failure. In 1881, when these pumps were supposed to be delivering 17 cubic metres per second, the foundations of the pump house were not laid. Very great difficulties were encountered, and when at last the Archimedean screws were got to work they failed hopelessly.

'The convention of 1881 above mentioned gave an extension of time, but it was of no use: the system was bad, and nothing would make it good. By the convention of 1883 the company undertook to remodel the Khatatba station, and to guarantee 29 cubic metres per second.

'The firm of Farcot, of Paris, was employed to supply the new pumps, and they sent out exceedingly fine machinery. Three Archimedean screws were retained, and the remaining seven removed and replaced by five direct-acting centrifugal pumps, each driven by a separate Corliss engine. Nor did the new installation work smoothly at first. Lubrication of such immense pumps gave trouble; but by the end of the season of 1885 all difficulties were overcome, and the five pumps would lift 29 cubic metres per second. The maximum volume of water lifted by all the pumps together, including the three Archimedean screws, was under 35 cubic metres per second. The pumps continued to work without hitch or hindrance until finally stopped on the 10th April, 1890, since which they have never been used.'

As has been stated elsewhere, the causes which led to these pumps being no longer required after 1890, were the restoration of the Barrage and of the Rayah Behera."

The following quotation is from Sir Hanbury Brown's Report for 1901 :—

" Before the weirs (downstream of the Delta Barrages) were completely finished, another large work was taken in hand. A barrage on the Damietta branch at some point between Zifta and Samanud was proposed some years ago, and a design for it was made by Mr Willcocks as one of the Reservoir group of works, before the weirs had even got beyond the stage of vague suggestion. The construction of the weirs has to some extent diminished the necessity for a barrage on the Damietta branch, but the advantages to be derived from such a work are still sufficiently great to justify its construction. In spite of the power the weirs give us of raising the water surface above the Delta Barrage to the level that gives nearly maximum discharges at the canal heads, taking off above it, as early as the last week in July, the demand for water is everywhere so great that rotations cannot be taken off until after 15th August. On p. 174 of the second edition of *Egyptian Irrigation* Mr Willcocks, after pointing out that the August waters of the Nile are particularly rich in fertilising mud, expresses his opinion that 'any canal which needs rotations in August to enable it to carry water to its tail is quite inefficient.' Though the expression may be a little too strong, he is probably right in suggesting as ideal a system of canals so disposed that, from the beginning of August, a plentiful supply of the rising flood water can be given at all points throughout it without rotation, until everybody is satisfied. With the Zifta Barrage in operation we shall obtain a new point of supply from the river to the canals at about the centre of their lengths, so that, at the end of July, we shall have the northern parts of the Delta drawing from canals flowing with such discharges as will satisfy all demands, and there will be no necessity to keep on rotations on the canals of the southern half of the Delta in order to force water forward to the north. This we may confidently predict as one advantage to be gained.

It is more difficult to be precise about the use that will be made of this barrage in summer. With an abundant supply of summer water, it will doubtless be found most convenient to use the Damietta branch as being one of the main irrigation channels taking off from above the Delta Barrage, and to apportion to it its proper share of the water to be distributed to the north parts of the Delta by the canals taking off from the river above the Zifta Barrage. With such scanty summer supplies as we have had in 1900 and 1901, and are expecting again in 1902, it would probably be found more economical of water to pass the available supply forward by the canals, and *not* to utilise the river channel for that purpose. But as the Aswan Reservoir will come into operation simultaneously with the Zifta Barrage, such severe conditions of summer supply need not be considered.

It will be one of the functions of this barrage to intercept the discharge of the river due to springs along the river bed and to infiltration from the bordering lands between the barrage and Zifta ; and to make this supply also available for purposes of irrigation. Recent experience has, I consider, shown that the discharge due to such sources has been overestimated in previous reports. Moreover, the heading up that will take place at the Zifta Barrage before such water can be utilised will itself tend to check the springs and lessen the volume due to their working, so that we must be cautious in our estimates of what results may be expected on this account.

The barrage is designed to hold up 4 metres of water. It will have fifty openings of 5 metres width with abutment piers between each group of ten."

If the Zifta Barrage had been utilised solely for the object for which it was designed, it would have been an unmixed blessing; used, as it has been, to maintain at a high level the water of the Damietta branch through the summer, with the aid of a subsidiary weir, it has been a nuisance to the country lying around Zifta.

67. **Historical, Upper Egypt.**—From time immemorial the Fayum Province enjoyed a small amount of perennial irrigation from the seepage water entering the Yusufi Canal as it traversed the Middle Egypt basins. This supply was very considerably increased when the Ibrahimia Canal was completed.

We now quote from the second edition, which gives the history up to 1897:—

"Perennial irrigation direct from canals is confined in Upper Egypt to 587,000 acres.

| | Acres. |
|---|---|
| Assiut Province | 33,000 |
| Minia ,, | 166,000 |
| Beni Suef ,, | 53,000 |
| Fayum | 329,000 |
| Giza | 6,000 |
| | 587,000 |

Of this area 6000 acres lie on one of the Delta canals and are not in connection with the Upper Egypt canals; the area is thus reduced to 252,000 acres in Assiut, Minia, and Beni Suef on the Ibrahimia Canal proper, and 329,000 acres in the Fayum on the Yusufi Canal, or 581,000 acres in all. The whole of the Province of the Fayum is under perennial irrigation, while in the other three provinces there is a narrow strip of land bordering the Nile in the extreme northern part of Assiut and the southern half of Minia; in the northern half of Minia the strip is broad and embraces the greater part of the Nile Valley, while in Beni Suef Province the strip is a narrow one south of the town of Beni Suef, but widens out considerably in the rich lands north-west of the town.

The Ibrahimia Canal is the only perennial canal in Upper Egypt which takes its water direct from the Nile. It was completed in 1873 by Baghat Pasha. Taking out of the Nile near Assiut, it runs for 268 kilometres along the high land near the river. It also supplies water to the Fayum with a summer discharge varying from 7 to 20 cubic metres per second by the Yusufi Canal. The discharge of the Ibrahimia Canal varies from 25 to 100 cubic metres per second in summer, according to the condition of the river. The area commanded by the Ibrahimia is protected from the basins by longitudinal banks called 'Mohit,' and all land west of this bank is under basin irrigation. In addition to supplying summer water to the lands enjoying perennial cultivation, the Ibrahimia supplies red water in flood to the basins by eight heads discharging into the basins. These heads serve also as escapes for the excess water in the Ibrahimia in flood."

See paragraph 77 for a description of the Ibrahimia Canal as it is to-day.

In 1902 the Aswan Reservoir was completed, and at the same time the Assiut Barrage on the Nile at the head of the Ibrahimia Canal was built and a regulating head for the canal itself. The canal was thus made independent of the fluctuating level of the Nile in summer and rendered capable of taking in the discharge sent down from the Aswan Reservoir in that season. By regulating on the Assiut Barrage in flood the flood supplies of the Ibrahimia lands have been rendered independent of the level of the Nile in flood.

Heavy works in the direction of widening and deepening the lower reaches of the Ibrahimia Canal, converting 405,000 acres of basin land into perennially irrigated land, and adding large areas to the Fayum, have been undertaken since 1897. The discharge entering the Ibrahimia Canal in summer has been increased from 55 to 145 cubic metres per second, and the area commanded on the Canal itself, independently of the Fayum, from 213,000 to 618,000. The whole of the 252,000 acres of land classed as perennial on the Ibrahimia Canal were not really so, and an area of 213,000 would more truly have represented the facts of the case.

We now quote from the beginning of a paper kindly written by Mr J. B. Ireland, the Director-General of the Conversion Works, who succeeded H. E. Ismail Pasha Sirry, when the latter became Minister of Public Works :—

"The conversion works in Middle Egypt cover all the chain of basins situated on the west of the Nile in the northern part of Assiut Province and in Minia, Beni Suef, and Giza Provinces. Of this tract, however, a narrow strip situated between the old Lebbeini Channel and the Western desert in the northern part of Beni Suef Province and in Giza Province, is left under basin irrigation.

The following table gives the names of basins, their year of conversion, and when handed over to the respective circles.

Actual constuction work started in 1901, but, previous to that, cross levelling of the land had to be done and data collected of existing canals and regulators.

[Table

TABLE 179.—BASIN CONVERSION DATES.

| Name of Basin. | Name of Province. | Year Conversion started. | Name of Circle handed over to | Date handed over. | Year Extra Land Tax was first collected. |
|---|---|---|---|---|---|
| Tanuf . . . | Assiut | 1901 | Assiut Barrage Circle | Dec. 1, 1902 | 1903 |
| Tanda . . | „ | „ | „ | „ | „ |
| Ashmunein . . . | „ | „ | „ | „ | „ |
| Itka . . . | „ | „ | „ | „ | „ |
| Tahnashawi . | Minia | 1902 | Fourth Circle | „ | 1904 |
| Kuran. . . | „ | „ | „ | „ | „ |
| Tahawi . . | „ | „ | „ | „ | „ |
| Deri . . . | „ | 1903 | „ | „ | 1905 |
| Mankatin . . | „ | „ | „ | „ | „ |
| Membal . . | „ | „ | „ | „ | „ |
| Bardanohi . . | „ | „ | „ | „ | „ |
| Garnusi . . | „ | „ | „ | „ | „ |
| Salakusi . . | „ | „ | „ | „ | „ |
| Kom el Saayeda . | „ | 1904 | „ | Dec. 1, 1906 | 1906 |
| Hosha Marko . | „ | 1905 | „ | Aug. 15, 1905 | |
| „ Absug . | „ | „ | „ | „ | |
| „ Talt. . | „ | „ | „ | „ | |
| Sultani . . | Beni Suef | 1904 | „ | Dec. 1, 1906 | 1906 |
| Nina . . . | „ | 1905 | „ | „ | 1907 |
| Nuera. . . | „ | „ | „ | „ | „ |
| Bahabshin . . | „ | 1906 | „ | Aug. 1, 1907 | 1908 |
| Koshesha . . | „ | „ | „ | „ | „ |
| Rikka . . | „ | 1907 | „ | June 12, 1908 | 1909 |
| Moarkab . . | Giza | „ | „ | „ | „ |
| Tahma . . | „ | „ | „ | „ | „ |
| Dahshur . . | „ | 1908 | Delta Barrage Circle | Aug. 1, 1910 | 1910 |
| Sakkara . . | „ | „ | „ | „ | „ |
| Shabramant . | „ | „ | „ | „ | „ |
| Tersa . . . | „ | 1909 | „ | „ | 1911 |
| Manshidia . . | „ | „ | „ | „ | „ |
| Iswid . . . | „ | „ | „ | „ | „ |

68. **Perennially Irrigated Lands in 1897.**—The following notes were made in 1895, 1896, and 1897, and published in the second edition of this work :—

"*Assiut Province*—The Ibrahimia Canal has its head in this province. It traverses the northern half of the province with its water surface in soil in winter and summer, at a very convenient level for lift irrigation. This tract has the advantage of having situated in its centre the Ashmunen mounds with a plentiful supply of manure. The best of the Daira property is in this province. The only lands salted and deteriorating are those north of Ashmunen where high-level canals traverse sandy soil and saturate it.

*Minia Province.*—The perennially irrigated tracts in the southern half of the province have a general width of 3 kilometres, and in the northern of 8

kilometres. Where the width is narrow one main canal and one drainage cut running north and south are sufficient; but in the broad tract there should certainly be two, if not three, drainage cuts running north and south. The present single drainage cut is totally inadequate. These drainage cuts should not be only for drainage water but also for escape water from the canals and watercourses. Water should always be flowing. It is the dammed-up stagnant water at a high level in the canals and watercourses which does so much harm. While the canals and watercourses are being used for irrigation, the flow is healthy, but when irrigation is over, the water impounded in the canals and watercourses is not cut off at their heads but kept trickling down, and all these channels remain full of water at a high level in season and out of season. If the drainage cuts or escapes spoken of above were made and kept clean, and a system of weekly rotations adopted for the canals, by which they ran one week and were closed the next, there is little doubt that perennial irrigation would not be accompanied with the deterioration we see in this province, especially in the western half of the broad tract. The drains should, moreover, be provided with pumps to lift water into the tail escapes when the Nile and the basins in flood do not permit of free flow, unless the levels allow of drainage on the methods adopted in the valley of the Po, and explained in the chapter on drainage. The lands which were originally poor and have been thrown out of cultivation by perennial irrigation should be put under basin irrigation again and thoroughly renewed before they are provided with perennial irrigation for a second time. Mr Wilson would like to see all lands which have deteriorated from over-cropping or over-irrigation put under basin irrigation every fourth year by rotation. Any definite system thoroughly taken up and carried out would be better than the plan of allowing great areas of good land to deteriorate year by year without an effort being made to save them from ruin. More blame possibly attaches to the proprietors than to the Government, but the Government is equally interested with the proprietors and could do much if it was so inclined.

*Beni Suef Province.*—See paragraph 50, *Beni Suef.*

*Fayum Province.*—The development of this province depends on a liberal and early supply of flood water and the doubling of the capacities of the canals. Some of the canals should have their sections trebled. Since the Nile deposit is seldom more than 4 or 5 metres in thickness, and generally very much less, while it overlies as a rule bitter salts, it is very liable to be salted. The perennial irrigation might with advantage be confined to the fertile high-lying plateaus, while the swamped and salted valleys might be reconverted into basins, and the level of Lake Kurûn allowed to rise again to its 1884 level.

The land lying on the severe slopes bordering on the lake has deteriorated very considerably wherever the higher lands are heavily irrigated. The only remedy for these lands is deep drains and canals running diagonally to the slopes, and cutting off the lands below them from the excessive saturation originating in the irrigation on the tops of the plateaus. Drains in the direction of the slope are valueless, they do not cut off the saturating waters travelling down the slopes.

The Gharak depression, which has deteriorated completely and which cannot be drained by ordinary methods, should have its summer supply completely cut off, and be provided with a plentiful supply in flood by rotation, and a spring supply in winter also by rotation. During summer the hot Egyptian sun should be allowed to dry up the land thoroughly. Rich crops of sorghum followed by barley

and clover would be better than the barren wastes of salt land which alone are met with now.

*Behera Province.*—South of the sand dunes bordering the Mediterranean there used to be three lakes, Abukir, Edku, and Mareotis. Lake Abukir has been drained by an English company and is being gradually reclaimed; Lake Edku is being gradually dried up by the Government to allow of the drainage cuts tailing into it having an efficient outlet; and Lake Mareotis has had powerful pumps erected on it to maintain its level at 2 metres below mean sea. The present areas of Lake Edku and Mareotis may be taken as 60,000 and 70,000 acres respectively, making a total of 130,000 acres. Lake Edku has an outlet into the Mediterranean at Madia.

The Behera Province has two strips of very good land in addition to the rich lands at the south-east corner, but the province generally is poor and needs considerable sums to be spent on its development. The best land follows the line of the ancient Canopic branch of the Nile with its head at Kafr Bulin. The trace of the Canopic branch can be easily followed down the Abu Diab Canal past Saft el Muluk to Dinshal, Karakas, Gattâs, and Kariun, finally tailing into Abukir Bay west of Madia. When the Khatatba Canal was remodelled, it was unfortunate that its new alignment was not taken down this line to Damanhur. Its present channel on either side of the railway is an unfortunate one, as it is taken in high embankment across the drainage of the country, and the only place where it is in digging is where the railway passes close to the ancient Canopic branch. All drainage east of the Canopic branch goes naturally to Lake Edku, and all drainage west of the Canopic branch goes naturally to Lake Mareotis. The second strip of good land follows the line of the Rosetta branch of the Nile. No canal in this province except the Mahmudia has an escape, so that it is very unfortunately situated in that respect. The drainage has been most thoroughly and efficiently taken up, but drainage cuts without escapes for excess canal water are of no permanent value.

The irrigation of the province is effected by three main canals, the Rayah Behera from upstream of the Barrage, the Khatatba from a point some 45 kilometres down the Rosetta branch, and the Mahmudia Canal from a point of 40 kilometres south of Rosetta. The Rayah Behera supplies the water in summer and winter, while the other two, principally the Khatatba, in flood. The Mahmudia Canal was dug by Mohamed Ali in 1819–20 with the object of opening a direct waterway between Cairo and Alexandria, supplying the latter town with water, and providing for summer irrigation. This canal was fed in a novel way. An area of 10,000 acres to the south of Atfeh was surrounded by a dyke, filled with water from the Nile in flood between the months of August and October, and turned into a reservoir for supplying winter and summer water to the Mahmudia Canal. Owing to the shallowness of the reservoir, the short interval of time within which it could be filled, and the long interval of time it had to be drawn upon, with all the waste of evaporation and absorption through nine months of the year, the reservoir was found to be insufficient, and in 1849 it was replaced by pumps at Atfeh and Khatatba.

This province has been in the past an excellent example of the costliness of pumping into the main feeder canals from the Nile in summer, instead of building permanent weirs across the Nile and taking the water by gravitation. The advantages claimed for pumping were:—

1. No necessity for dredging the canals, as the water would enter at a high level from the pumps.

2. Flush irrigation in summer.

3. The certainty of the pumps as compared to the weirs.

On the matter of cost there was never any question, for the supply of 50 cubic metres per second by pumping into one province in summer cost the State £50,000 per annum in round numbers, and the cost of raising the 400 cubic metres per second needed for Lower Egypt would have amounted to £400,000 per annum. Weirs can be built on the Nile for £800,000 apiece, and if Egypt had had no weirs, two such weirs could have ensured the whole supply being utilised with an annual outlay of £15,000. Interest on £1,600,000 at 5 per cent. would have represented £80,000 per annum, and maintenance £15,000, bringing up the total to £95,000 per annum as against £400,000 per annum for pumping. The question in Egypt, however, was much simpler, for the hitherto condemned weirs known as the barrages existed, and Sir Colin Scott-Moncrieff had them repaired by Colonel Western for £500,000, and so secured summer irrigation to Lower Egypt at a prime cost of money only slightly in excess of what would have been the annual outlay on pumping.

It was found in Behera that there was no diminution in the money spent on dredging, as the dredging of the three canals was as necessary as ever on account of navigation, water supply in winter, and the fear of allowing silt to accumulate. The perpetual dredging of the canals prevented flush irrigation in summer in their upper reaches, while in their lower reaches they give as much flush irrigation to-day, now that they are fed by gravitation, as they did in the old days of pumps. General flush irrigation in summer is, however, a curse and not a blessing. Looked at from the point of view of security, weirs have proved themselves to be as reliable as the gigantic pumps required to lift the quantities of water needed for important irrigation canals irrigating a million and a half of acres between them."

The following report on the Behera Province was kindly written for the second edition by the late Mr N. E. Verschoyle, Inspector of Irrigation, in October 1898. It gives the views of a very sound irrigation officer.

"The province of Behera contains some 700,000 acres of cultivable land of very varying quality, the chief factor affecting the latter being its elevation.

The northern portion of the province lies so low, that minute differences in elevation have marked effects on the quality of the soil.

The province derives its water supply from the Rayah Behera Canal, taking off on the west of the Rosetta branch above the Barrage.

During the flood season the Rayah Behera is supplied through the Khatatba feeder, situated 40 kilometres below the Barrage.

The result of this practice is to diminish the silt deposit in the upper reaches of the canal, and to relieve its sandy slopes from the erosive action of the flood supply. During flood a further supply is also drawn in by the Mahmudia and Rosetta Canals, whose heads are some 150 kilometres below the Barrage.

The Rayah Behera and its continuations, the Khatatba and Sahel Markaz Canals, run down the eastern limit of the province for 147 kilometres to Atf, where they tail into the Mahmudia Canal, the principal irrigation and navigation channel

of the province. The Mahmudia Canal is fed at its head through the Sahel Markaz, also during flood time directly from the river through the head locks, and again at kilometre 15 through the Khandak Sherki Canal. The Rayah Behera, Khatatba, and Sahel Markaz form one system. At 80 kilometres from the Rayah Behera head comes the Kafr Bulin regulator, above which take off the Nubaria and Abu Diab Canals, each of which, with its branches, forms a system. Thirteen kilometres below Kafr Bulin on the Khatatba Canal comes the Kafr Eis regulator, where take off the Khandak Canals, which run north-west along the Cairo-Alexandria Railway, finally uniting and forming the main feeder of the Mahmudia Canal; and the West Gannabia, tailing into the Daheri Canal, which latter channel has a head in the Khatatba 14 kilometres below Kafr Eis. The Khandak Canals, the West Gannabia, and the Daheri form systems 4 and 5. The sixth system is formed by the Mahmudia Canal. The following table gives the chief details of the systems described above.

At the head of the Mahmudia Canal there is a pumping station on the river which formerly raised the whole supply of the canal, and is now occasionally used for short periods in years of bad supply. The installation of pumps consists of eight scoop-wheels 10 metres in diameter, and 3·00 to 3·60 metres in width, driven by two compound engines of 400 horse-power each, and four beam engines of 220 horse-power each. The eight wheels can lift from 23 cubic metres to 35 cubic metres per second, according to the lift, which varies from 2·20 to 2·70 metres.

TABLE 180.—CANAL SYSTEMS, BEHERA PROVINCE (1897).

| Name of System. | Area commanded, in acres. | Length of Canal, in kilometres. | | | Discharges, cubic metres per second. | |
|---|---|---|---|---|---|---|
| | | Main. | Minor. | Total. | Maximum. | Minimum. |
| Rayah Behera and Khatatba | 89,607 | 147 | 78 | 147 | 200 | 78 |
| Nubaria | 199,325 | 81 | 156 | 237 | 38 | 10 |
| Abu Diab | 78,540 | 75 | 84 | 159 | 15 | 5 |
| Khandaks | 75,805 | 77 | 124 | 201 | 55 | 26 |
| West Gannabia and Daheri | 47,243 | 36 | 30 | 66 | 17 | 7 |
| Mahmudia | 260,840 | 76 | 243 | 319 | 58 | 35 |
| Totals | 751,360 | 492 | 715 | 1207 | | |

For purposes of drainage, the province is divided into two systems—the eastern system, which discharges into Lake Edku, where it is disposed of by evaporation during the spring and summer, and in the autumn and winter overflows into the sea; and the western or Mareotis system discharging into Lake Mareotis, from whence, as soon as evaporation is unable to balance the discharge, it is pumped into the sea. £200,000 has been spent during the past two years in remodelling and extending the drainage system of the province, which was quite inadequate. Owing to lack of funds for construction or maintenance, the channels had been

made of utterly inadequate section, and had, moreover, been allowed to choke badly. Another £230,000 at least is required still to provide a fairly complete system of drains.

Immediate results have followed the expenditure of 1897 and 1898, land untouched before coming under cultivation, and cotton replacing rice. The following table gives the leading details of the two systems.

A main drain discharges directly into the lake, a secondary drain into a main drain, and a tertiary into a secondary drain.

TABLE 181.—DRAINAGE SYSTEMS, BEHERA PROVINCE (1897).

| Name of System. | Area served, acres. | Length of Channel, in kilometres. | | | | Aggregate Bed-Widths of Outfalls, metres. |
|---|---|---|---|---|---|---|
| | | Primary. | Secondary. | Tertiary. | Total. | |
| Edku | 383,148 | 82·0 | 107·9 | 94·4 | 284·3 | 43 |
| Mareotis | 379,085 | 105·2 | 121·5 | 47·2 | 273·9 | 42 |

It must be borne in mind that, owing to the small depths, the aggregate bed-widths above only mean a sectional area of water way of about 54 square metres. The sectional area at head of Rayah Behera in August is 205 square metres with a velocity 1·0 per second, while the sectional area at Khatatba in flood is over 300 square metres. Part of the discharge due to the latter area escapes back to the river by the canal escapes. It will, however, be evident from the above that the drainage outfalls require enlargement.

The installation of pumps at Mex, which serve to keep down the level of the Lake Mareotis for six months of the year, will, when the work now in progress is completed, consist of the following pumps and engines:—

TABLE 182.—MEX PUMPING STATION (1897).

| Pumps. | Engines. | Daily Discharge for Average Lift of 3 metres. |
|---|---|---|
| | | cubic metres. |
| Two Gwynne's Invincible centrifugal pumps, horizontal shafts, 48″ pipes. | Two horizontal compound engines, each 170 I.H.P., with surface condensers. | 500,000 |
| Five Farcot's pumps, centrifugal, with vertical shafts. Discharge pipes 5·0″ to 8·4″ diameter. | Two horizontal engines, each 350 I.H.P., with jet condensers and Corliss valves. | 2,500,000 |
| Total discharge per day . . . . . | | 3,000,000 |
| or 35 cubic metres per second. | | |

The following table gives the quantities pumped during the last four seasons and the expenditure incurred.

The cost of pumping per million cubic metres may be taken as £27, there being hardly any difference between the Gwynne's and Farcot's in this respect. The figures in column 3 of following table do not agree with this statement, because, up to date, the Gwynne's pumps have been run by a contract under which the cost of pumping one million cubic metres came to £51. It is evident from the figures for actual cost of pumping given above, that a large annual saving will be effected by working all the pumps directly by Government, as has been done in the case of the Farcot's pumps. The cost given per million pumped is that obtained with best Cardiff coal, costing £1·032 per ton delivered at pumping station, which is a favourable rate.

| Season. | Quantity pumped, in cubic metres. | Expenditure incurred. |
| --- | --- | --- |
| 1894–95 | 88,747,236 | £4,605 |
| 1895–96 | 175,078,166 | 7,838 |
| 1896–97 | 216,994,810 | 8,068 |
| 1897–98 | 227,431,000 | 8,861 |

The question of drainage in the province is rendered a difficult one, owing to the low level of the ground to be drained with reference to the sea.

The lakes which serve as outfalls are very shallow. Drains with great bed-widths, small depths, and slight gradients are obligatory. The first cost of the channels is therefore heavy, and what is worse, their maintenance is costly, the shallow channels with mere dribbles of water in them for a considerable portion of the year being very liable to choke with weeds. These difficulties as regards construction are being faced. The future of the agriculture of the province depends largely on the liberality shown in allotting funds for the proper maintenance of the fine series of drains now being made."

"*Menufia Province.*—The proportion of resident proprietors is large, the population dense, the land rich, cattle plentiful, and the cultivation superb. One of the most prosperous agricultural communities in Egypt inhabits this province. The irrigation is generally lift through winter and summer, and the soil has not in consequence deteriorated.

This province is well provided with canals, and as they are generally in soil in winter and summer, no drainage cuts are needed and none exist. Deterioration of soil has begun in a few places where irrigation has begun to be flush throughout the year, but such areas are small and could very easily be given that lift irrigation in summer which is the life of the province.

*Gharbia Province.*—The southern parts of the province are similar to Menufia, but in the north the only really important crop is cotton, and everything is subordinated to it.

South of the sand dunes bordering the Mediterranean lies Lake Borollos with a permanent area of 180,000 acres. During flood the lake rises and floods the

adjacent country. The opening into the sea is near the town of Beltim. The question of the lake is discussed in the chapter on Drainage and Land Reclamation.

The northern half of this province is very difficult to irrigate in summer, as all the canals which supply it with water have to run the gauntlet of the wealthy and serried proprietors of Menufia and of Southern Gharbia itself. Much money has been spent in widening and deepening some of the main canals, but very much remains to be done. All the main canals should be given such sections that they might easily carry their winter and summer supplies in soil, and so ensure the irrigation of the north without injury to the rich middle strip of the province, which was more prosperous and wealthy in the old lift irrigation days than it is to-day. In addition to this widening and deepening of the canals (especially the great central artery the Kasad Canal) the Damietta branch should be provided with a weir or barrage at Samanud and a secondary feeder taken to the Bahr Shebîn downstream of Rahbain regulator. This increased supply might be put in communication with the central part of the Delta in the extreme north by means of a special canal connecting the Bahrs Tira and Mallah, north of Ibshan. A suitable work could be built at Samanud for £350,000, which would not only utilise the 20 cubic metres per second of subsoil springs which filter into the Damietta branch, but also pass directly to the thirsty lands in the north the summer supplies needed for them without unduly filling the existing canals in their upper reaches in Menufia and Southern Gharbia. As no sound and reliable work could be built in the Rosetta branch near the sea under an expenditure of £750,000, it would be better to continue the construction of the temporary earthen dam on this branch at Mehallet Amir, which can be done for less than £10,000, and is not needed every year. The rising flood sweeps away and obliterates all trace of this dam every year that it is constructed.

Most of the canals are well provided with escapes, and the distribution of red water in flood is generally satisfactory. The department has recently begun a system of weekly rotations in winter and summer, which will do an immense amount of good if rigidly enforced and if the canals in the middle reaches have their sections increased. There is no fear of such canals silting in their sections in flood if the escapes are kept fully open.

The drains are subdivided into twelve systems, and generally follow the depressions between the deltaic canals. In the north-east of this province there is a large area of waste land which is never covered in flood. This land has in great part been gradually converted into a salt plain, from which the salts are carried by the prevailing north-west winds on the lands lying immediately south of them. The reclamation of these latter lands is in consequence very difficult, and will never be accomplished until the salt plains have been covered by water. This point might be remembered when the drying up of Lake Edku is considered.

*Kaliubia Province.*—This is another province where the irrigation in winter and summer is generally lift, and the land in consequence in excellent preservation. The same remarks apply to it as to Menufia, only in a more moderate degree, because the proportion of resident proprietors is not nearly so large.

*Sharkia Province.*—Between the provinces of Sharkia and Dakahlia on one side and the sand dunes bordering the Mediterranean on the other lies the Menzala

Lake, with a permanent area of 490,000 acres. The opening into the sea is at Gemela, west of Port Said. During flood the lake rises and floods the adjacent country. The question of the lake is discussed in the chapter on Drainage and Land Reclamation.

The principal crops are cotton, clover, wheat, Indian corn, rice, barley, beans, and ground nuts. The date palm is very extensively cultivated along the edge of the desert.

The summer supply of this province has very considerably benefited from the barrage repairs. The new Rayah Tewfiki, constructed by Colonel Western, supplies this province and Dakahlia with a very liberal supply of water. Extensive areas of sandy desert have been recently reclaimed and planted with ground nuts. With the liberal supplies sent down the canals all the high-lying lands have greatly benefited, but much of the low-lying land has deteriorated. The area irrigated from wells in this province was very extensive in the past, as the desert sand is close to the surface and buried under insignificant depths of clay over large tracts. The high-level perennial canals have damaged the whole of this land. To enable this province to enjoy the full benefits of perennial irrigation, every canal should, I think, be provided with free flow in flood, and widened and deepened in its middle reaches, escapes should be multiplied everywhere, and the summer supplies kept in soil wherever possible, with rigid weekly rotations through the winter and summer. The Wadi Tumilat near Tel el Kebir, which has been wellnigh ruined by the high-lying Ismailia Canal, constructed by the Suez Canal Company, gives warning of the damage which can be done by high-lying perennial canals in unsuitable soil. If the canals, which are, I think, the real source of the harm, were looked to and scientifically treated, three-quarters of the drainage cuts might not be needed at all.

The drainage cuts in this province are very plentiful, but there is a lamentable lack of red water in flood at the tails of nearly all the canals. If the extensive salted lands in the north of the province are ever to be reclaimed, the amount of red water reaching them must be multiplied by ten.

*Dakahlia Province.*—The remarks which have been made about Sharkia apply to the southern half of this province, especially to the tracts on the Khazzan and Bohia Canals. The country wants escapes for red water rather than drains. The Bahr Sogair, in the north of the province, is an excellent example of a canal with free flow in flood and general lift irrigation in winter and summer. The finest crops in the province and the best-preserved lands are met with on its banks. It is in every way a striking contrast to the Bohia, where exactly the opposite conditions prevail. The water surface of the Bohia might be lowered 2 metres in summer and 1 metre in flood with the greatest advantage. The upper reaches of the Tanah and Gabbada deltaic canals, occupying the highest lands in their neighbourhood, with the Tanah-Gabbada drain between them occupying the lowest land, are some of the best examples in Egypt of well-designed canals and drains in their proper positions, just as the Bahr Fakûs and Bahr Sân are the worst examples. The lower reaches of these canals have been converted into drains with disastrous consequences. Colonel Ross's saying of a red-water famine being the greatest calamity which can overtake any part of Egypt might be posted with advantage in every inspector's office in the country.

Take the whole of the basin tracts of Egypt, and compare them with the

perennially irrigated tracts, and we are met with the startling fact that there is not between the renting values a greater difference than 15 per cent. This is doubtless due to the fact that basin irrigation, imperfect as it is in places, has attained a far higher degree of perfection than perennial irrigation. The perfection of perennial irrigation and its scientific treatment on lines such as those attempted to be traced by me in this book, are the problems which the Irrigation Department has to solve. If it cannot solve them within a reasonable time, the improvement of large areas of favourably situated land to whose amelioration still larger areas of land unfavourably situated have been sacrificed, and the reclamation of extensive wastes at the high price of the permanent abandonment of still more extensive wastes which basin irrigation could have reclaimed, will bring us face to face with the fact that the basin irrigation of Egypt, devised by the ancient Egyptians themselves thousands of years ago, and in full vigour to-day, was better suited to the country and had more permanency than the system of perennial irrigation, whose mushroom growth has had the whole strength of the Government on its side, but has had Nature against it."

69. **Duty of Water.**—M. Barois, in his excellent *Les Irrigations en l'Egypte*, gives interesting historical information about the discharges needed for summer irrigation, from which the following is abridged:—

"The International Commission for the study of the Suez Canal, when consulted by Ismail Pasha, considered a discharge of 20 cubic metres per acre per day as sufficient. Linant de Bellefonds in one place states that 16 cubic metres for cotton and 24 cubic metres per acre per day for rice should be assured, while in another place he says that cotton will take up to 30 cubic metres per day and rice 36. Sir John Fowler, in 1875, advised the Khedive that 21 cubic metres per day was needed by cotton. In 1883 the Ministry of Public Works put the figure at 23 cubic metres. In 1887 the Ministry considered 30 cubic metres per day as necessary for cotton. In Sir William Willcocks' official report on the Aswan dam in 1894, the figures were as follows:—

| | | | | | |
|---|---|---|---|---|---|
| Summer irrigation— | | | | | |
| Cotton | 17 cubic metres | per acre | per day | in the field. | |
| " | 22 | " | " | " | at the canal head. |
| Rice | 40 | " | " | " | " |
| Flood irrigation— | | | | | |
| Maize | 25 | " | " | " | " |
| Cotton | 25 | " | " | " | " |
| Rice | 40 | " | " | " | " |
| Winter irrigation— | | | | | |
| Wheat, clover, &c. | 11 | " | " | " | |

These figures applied to Lower Egypt; for Upper Egypt 33 per cent. were to be added to allow for the greater dryness and heat of the climate."

The irrigation reports for the different years give varying figures.

In the project for the conversion of the Middle Egypt basins to perennial

irrigation H.E. Ismail Pasha Sirry used the following figures at the canal heads:—

| | | | |
|---|---|---|---|
| Summer: Cotton, sugar-cane, etc.— | | | |
| First watering | 32·2 cubic metres per day per acre. | | |
| Second „ | 24·6 | „ | „ |
| Subsequent „ | 17·33 | „ | „ |
| Flood: Millets and maize— | | | |
| First watering | 31·50 | „ | „ |
| Subsequent „ | 24·26 | „ | „ |
| Winter: Wheat, beans, etc.— | | | |
| First watering | 28·00 | „ | „ |
| Subsequent „ | 13·55 | „ | „ |

During 1903 and 1904, one of us undertook a series of experiments to discover the quantity of water lifted by shadufs and sakias, and at the same time the quantity applied to the fields in different parts of Egypt in the different seasons. The net results were as follows:—

| | | | | | Cubic metres per acre per day. |
|---|---|---|---|---|---|
| Wheat | Sakia | irrigation | in Kena | in winter | 16 |
| Millets | „ | „ | „ | in summer | 28 |
| „ | Shaduf | „ | „ | in flood | 26 |
| „ | Sakia | „ | „ | „ | 27 |
| *Sugar-cane | Free flow | „ | in Minia | „ | 15–21 |
| *Cotton | „ | „ | „ | „ | 17–25 |
| Millets | „ | „ | „ | „ | 23 |
| „ | Sakia and shaduf | | in Giza | in summer | 25 |
| Cotton | „ | | „ | „ | 20 |
| „ | Pump | irrigation | „ | „ | 22 |
| „ | Tabut | „ | in Behera | in flood | 23 |
| Maize | „ | „ | „ | „ | 23 |
| Rice | „ | „ | „ | „ | 59 |
| Cotton | „ | „ | in Gharbia | „ | 19 |
| „ | Pump | „ | „ | „ | 19 |

Sharaki irrigation per acre per watering came to 700–1000 cubic metres.

The above quantities were delivered at the fields. To them have to be added the loss in the canals. Such losses in winter are small, and with our present high ground water the losses in summer are not heavy. If we put the loss in the canals at 5 cubic metres per acre per second in summer, we shall not be under the mark. In winter the losses may be neglected.

The following table gives the summer duties of water in Lower Egypt, taking the periods of irrigation as the Department calculates them, and taking an acre of rice as equal to two acres of cotton as they do.

* Rotations sometimes force people to give light waterings to complete their plots.

TABLE 183.—DUTY OF SUMMER WATER AT CANAL HEADS (IRRIGATION DEPARTMENT).

(From Government Reports.)

| Year. | Duty in cubic metres per acre per day. | |
|---|---|---|
| | Upper Egypt. | Lower Egypt. |
| 1899 | 31·8 | 26·0 |
| 1900 | 32·8 | 21·2 |
| 1901 | 26·5 | 26·8 |
| 1902 | 31·2 | 23·2 |
| 1903 | 38·1 | 25·9 |
| 1904 | 24·4 | 34·0 |
| 1905 | 28·4 | 25·8 |
| 1906 | 28·6 | 32·9 |
| 1907 | 34·8 | 28·4 |
| 1908 | 29·9 | 24·8 |
| 1909 | 50·5 | 28·4 |
| 1910 | 36·0 | 28·5 |
| 1911 | 36·1 | 26·4 |
| 1912 | 28·8 | 22·7 |

Allowing an acre of rice to be equal to 3 acres of cotton in water consumption, as recommended by Mr Gerald Dudgeon, Director-General of the Agricultural Department, and employing the figures given in the following paragraph for the mean discharges utilised, we work out the duty for Lower Egypt as follows:—

TABLE 184.—DUTY OF WATER IN SUMMER AT CANAL HEADS LOWER EGYPT (MODIFIED).

| Year. | Area under Crop in acres. | | Acres. Dry Crop, plus three Times Rice. | Discharge. | | Duty. Cubic metres per acre per 24 hours. |
|---|---|---|---|---|---|---|
| | Irrigated Area, less Rice. | Rice. | | Cubic metres per second. | Cubic metres per day. | |
| 1899 | 1,250,000 | 150,000 | 1,700,000 | 490 | 42,300,000 | 25 |
| 1900 | 1,280,000 | 40,000 | 1,400,000 | 300 | 25,900,000 | 18 |
| 1901 | 1,280,000 | 60,000 | 1,460,000 | 420 | 36,300,000 | 25 |
| 1902 | 1,290,000 | 80,000 | 1,530,000 | 410 | 35,400,000 | 23 |
| 1903 | 1,280,000 | 130,000 | 1,670,000 | 470 | 40,600,000 | 24 |
| 1904 | 1,300,000 | 140,000 | 1,720,000 | 510 | 44,100,000 | 26 |
| 1905 | 1,380,000 | 170,000 | 1,890,000 | 540 | 46,700,000 | 25 |
| 1906 | 1,360,000 | 140,000 | 1,780,000 | 640 | 55,300,000 | 31 |
| 1907 | 1,380,000 | 160,000 | 1,860,000 | 560 | 48,400,000 | 26 |
| 1908 | 1,390,000 | 170,000 | 1,900,000 | 500 | 43,200,000 | 23 |
| 1909 | 1,410,000 | 200,000 | 2,010,000 | 570 | 49,200,000 | 24 |
| 1910 | 1,380,000 | 230,000 | 2,070,000 | 600 | 51,800,000 | 25 |
| 1911 | 1,410,000 | 190,000 | 1,980,000 | 540 | 46,700,000 | 24 |
| 1912 | 1,410,000 | 200,000 | 2,010,000 | 460 | 39,800,000 | 19 |

In 1900 the cotton crop distinctly suffered for want of water, and in 1912 it also suffered, so we may clearly say that a duty of 18 to 20 cubic metres per acre per day is not sufficient. Mr Dudgeon considers 26 cubic metres as the quantity needed. We, however, basing ourselves on our years of experience and on the excellent results obtained in years like 1902, consider 24 cubic metres per second as a safe figure for Lower Egypt. In winter a watering of 350 cubic metres per acre once a month gives good results, which makes the winter duty 12 cubic metres per acre per day.

Summing up all the information at our disposal, and remembering that ground water in Upper Egypt is low in summer, causing heavy losses in the canals through absorption, higher in Middle Egypt, and high in Lower Egypt with insignificant losses through absorption, we consider that the following figures give a duty for water in Egypt which is reasonable and practical at the canal heads:—

TABLE 185.—PROPOSED SUMMER DUTY AT CANAL HEADS.

| | | | | | |
|---|---|---|---|---|---|
| *Upper Egypt—* | | | | | |
| Summer: | Cotton . . | 36 | cubic metres | per acre | per 24 hours. |
| „ | Sugar . . . | 40 | „ | „ | „ |
| Flood: | Millets . . | 36 | „ | „ | „ |
| Winter: | Wheat . . | 16 | „ | „ | „ |
| *Middle Egypt—* | | | | | |
| Summer: | Cotton . . | 30 | „ | „ | „ |
| „ | Sugar . . . | 36 | „ | „ | „ |
| Flood: | Maize . . | 30 | „ | „ | „ |
| Winter: | Wheat . . | 14 | „ | „ | „ |
| *Lower Egypt—* | | | | | |
| Summer: | Cotton . . | 24 | „ | „ | „ |
| „ | Rice . . . | 60 | „ | „ | „ |
| Flood: | Maize . . | 24 | „ | „ | „ |
| Winter: | Wheat . . | 12 | „ | „ | „ |

If in summer we assume one-seventh the whole area as under rice, we have as the summer duty for the whole of Lower Egypt $\frac{(24 \times 6) + (60 \times 1)}{7}$, or 30 cubic metres per acre per twenty-four hours.

The above figures apply to tracts enjoying perennial irrigation from perennial canals where there is always a very considerable rise of spring level. In the basin tracts of Upper Egypt, however, where irrigation is from pumps discharging into comparatively small canals, and where the ground water has not been raised seriously, an addition of 50 per cent. should be made to the figures at the beginning of Table 185. These figures of course apply to the discharges at the pumps.

The duty on all canals is greatly improved by the provision of suitably sized irrigation pipe outlets. These in Egypt are now being wisely put in by the Government, and in Upper Egypt the task has been assigned to Sir Robin Paul, who, with Mr Molesworth's permission, has kindly written the following note. We had the pleasure of going over some of his work, which needs as much geniality and kindly temperament to bring it to a satisfactory issue as it needs care and honesty.

*Note on Repiping of Canals.*

"The work of repiping canals has been carried on in Minia for the last four years, with the result that now practically the whole of the old area, *i.e.* that portion of the province lying east of the Western Moheit drain, has been repiped.

On the whole the landowners and cultivators may be said to approve of the work, in spite of the fact that every one of them has had his openings reduced, and the greater facility in getting water to the tails of canals, resulting from repiping, was plainly demonstrated during the last summer (1912) when water was very scarce.

The procedure varies greatly according to circumstances. Generally it takes the following form. Having decided on the canal to be repiped, a large map is prepared from the Survey Sheets, scale $\frac{1}{2500}$, of the whole area of land watered by the canal in question.

The existing openings with their diameters are then marked on the map, which is then taken by the official in charge of the work to the canal, where he meets by appointment landowners and Omdas.

It is then arranged as far as possible to suit the convenience of all parties what openings are to be left and what to be closed.

As large an area as possible is grouped together to water from one opening, provided that interested parties are agreeable; on the other hand, if a man owning more than eight acres insists on a pipe for his own use only, it is generally given him. Less than eight acres, unless under very exceptional circumstances, is not considered to deserve a private pipe.

Having decided on the number of pipes to be allowed in the area of a village and apportioned the different properties to their various openings, it only remains to measure the area and erect a pipe accordingly.

Attached will be found a list of pipe dimensions with the areas capable of being watered by each head apart.

It is not easy to lay down any rules *re* the levels at which pipes should be erected, owing to the varying conditions of land and levels, especially in the old basin area. In all cases the object aimed at is the even distribution of water and the satisfaction of the cultivators.

But given ordinary circumstances, the pipes are put so to have a head of 25 centimetres at H.W.L.

The Matai Canal may be taken as an instance of the benefits resulting from repiping.

This canal has heretofore given a great deal of trouble during rotations, owing to the high level of the land 10 kilometres from the head. This year, in spite of the very bad water supply, very few complaints were received from cultivators on this canal, and the curious thing is that those which were received came not, as

would be expected, from owners of high land on the lower and middle reaches but from the cultivators on the head reaches—who doubtless had in previous years had so much water that they were accustomed to cultivate 100 per cent. of their land with summer crops, to the detriment of their neighbours downstream of them.

Of course, as one would expect, difficulties crop up from time to time when landowners, generally among the wealthier people, are obdurate and prevent by force pipes being removed; these are people who have bought land from the Daira Sania and maintain that because when they took over the land there was a boiler or barrel in the head of their watercourse the Government has no right to alter the conditions of irrigation from such as they were when they bought the land.

This gives a lot of trouble at the time and causes delay; but though in some cases they threaten lawsuits, nothing ever comes of it.

TABLE 186.—LIST SHOWING THE DIAMETERS OF OUTLET AND INLET PIPES OF CANALS AND DRAINS, WITH THE AREAS SERVED IN ACRES.

| Diameter of Pipe. | | Area served in acres. | Diameter of Pipe. | | Area served in acres. |
|---|---|---|---|---|---|
| Inches. | Centimetres. | | Inches. | Centimetres. | |
| 4 | 10 | 10 | 20 | 50 | 510 |
| 5 | 12·5 | 20 | 22 | 55 | 625 |
| 6 | 15 | 30 | 24 | 60 | 760 |
| 7 | 17·5 | 45 | 26 | 65 | 900 |
| 8 | 20 | 65 | 28 | 70 | 1060 |
| 9 | 22·5 | 85 | 30 | 75 | 1220 |
| 10 | 25 | 110 | 32 | 80 | 1400 |
| 11 | 27·5 | 135 | 34 | 85 | 1590 |
| 12 | 30 | 165 | 36 | 90 | 1790 |
| 14 | 35 | 235 | 38 | 95 | 2000 |
| 16 | 40 | 315 | 40 | 100 | 2230 |
| 18 | 45 | 405 | | | |

As a proprietor's land may be at various levels and one pipe may be unsuitable for watering the whole area, he can be allowed as many irrigation pipes as the levels of his land warrant, provided the area on each pipe is not less than that shown on the above list, and also provided that no abuse is made of this facility, as many outlets weaken the banks; generally pipes should be so placed as to have not more than 25 centimetres' head on them."

70. **Summer Discharges utilised and available.**—Up to 1902 the Ibrahimia Canal took its water from the Nile at Assiut without any barrage on the river, and received a mean discharge of about 55 cubic metres per second, with a minimum of 25 cubic metres per second in 1889 and 1890, and a maximum of 100 cubic metres per second in 1879 and 1899. Since 1903 the Assiut Barrage has controlled the supply, and the discharge has risen to a mean of 145 cubic metres per second, with a

minimum of 120 cubic metres in 1903 and a maximum of 180 cubic metres in 1909.

In Lower Egypt the supply is controlled by the Delta Barrages.

| | | | | | | Discharge utilised. |
|---|---|---|---|---|---|---|
| Up to 1883, | the barrages | held up | to R.L. | 12·50 | metres . . . | 200 |
| 1884–1890, | ,, | ,, | ,, | 13·00 | ,, . . . | 310 |
| 1891–1900, | ,, | ,, | ,, | 14·00 | ,, . . . | 410 |
| 1901–1902, | ,, | ,, | ,, | 15·50 | ,, . . . | 415 |
| 1903–1910, | ,, | ,, | ,, | 15·50 | ,, . . . | 600 |

During these last eight years the Aswan Reservoir has been aiding the river.

Previous to 1884 the canals utilised less than half the water available; for 1884 to 1900 they utilised about four-fifths, while since 1901 the whole of the water available has been utilised.

The following table gives details of all this information.

It will be noted that in 1889 many carefully taken discharges showed that the total summer discharge of the Nile after the low flood of 1888 was 245 cubic metres per second. During this period the Albert Nile was sudded badly in the Sudd region. In 1899 sudd removal began, and in 1900 the supply after the low flood of 1899 was 305, or 60 cubic metres per second better than in 1889. Sudd cutting was completed by 1904, and since then the low supplies received in 1899 and 1900 have never been known. Egypt has benefited considerably from this beneficent work on the Upper Nile. This subject is returned to in CHAPTERS XII. and XIII.

[TABLE

TABLE 187.—WATER UTILISED AND AVAILABLE IN EGYPT IN SUMMER (in cubic metres per second).

| Year. | Upper Egypt. | Maximum Barrage Gauge in Summer. | In Canals. | Direct from Rosetta and Damietta Branches. | Total. | Total, Upper and Lower Egypt. | Supply available in the Nile in Summer from all Sources. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | Lower Egypt. | | | | | | |
| | | R.L. | | | | | | |
| 1877 | 65 | | 160 | 10 | 170 | 235 | 530 | |
| 1878 | 25 | | 110 | 10 | 120 | 145 | 250 | |
| 1879 | 100 | | 350 | 10 | 360 | 460 | 1500 | |
| 1880 | 80 | 12·50 | 240 | 15 | 255 | 335 | 900 | Delta Barrages holding up to R.L. 12·50 m. |
| 1881 | 35 | | 150 | 15 | 165 | 200 | 480 | |
| 1882 | 30 | | 130 | 15 | 145 | 175 | 380 | |
| 1883 | 50 | | 150 | 15 | 165 | 215 | 500 | |
| Mean | 55 | 12·50 | 185 | 15 | 200 | 255 | 650 | |
| 1884 | 70 | | 300 | 20 | 320 | 390 | 720 | |
| 1885 | 50 | | 300 | 30 | 330 | 380 | 390 | |
| 1886 | 60 | | 300 | 35 | 335 | 395 | 450 | Delta Barrage holding up to R.L. 13·00 m. |
| 1887 | 65 | 13·00 | 300 | 35 | 335 | 400 | 450 | |
| 1888 | 50 | | 300 | 35 | 335 | 385 | 470 | |
| 1889 | 25 | | 220 | 35 | 255 | 280 | 245 | Infiltration water drawn on. |
| 1890 | 25 | | 260 | 35 | 295 | 320 | 285 | |
| Mean | 50 | 13·00 | 280 | 30 | 310 | 360 | 430 | |
| 1891 | 30 | | 370 | 40 | 410 | 440 | 400 | Delta Barrage holding up to R.L. 14·00 m. |
| 1892 | 30 | | 330 | 40 | 370 | 400 | 360 | |
| 1893 | 50 | | 390 | 40 | 430 | 480 | 1000 | |
| 1894 | 50 | | 370 | 40 | 410 | 460 | 460 | |
| 1895 | 75 | 14·00 | 400 | 40 | 440 | 515 | 900 | |
| 1896 | 60 | | 380 | 40 | 420 | 480 | 730 | |
| 1897 | 80 | | 390 | 40 | 430 | 510 | 730 | |
| 1898 | 60 | | 380 | 40 | 420 | 480 | 440 | |
| 1899 | 100 | | 450 | 40 | 490 | 590 | 550 | |
| 1900 | 45 | | 260 | 40 | 300 | 345 | 305 | |
| Mean | 60 | 14·00 | 370 | 40 | 410 | 470 | 590 | |
| 1901 | 55 | 15·50 | 380 | 40 | 420 | 475 | 435 | Delta Barrage holding up to R.L. 15·50 m. |
| 1902 | 65 | | 370 | 40 | 410 | 475 | 435 | |
| Mean | 60 | 15·50 | 375 | 40 | 415 | 475 | 435 | |

TABLE 187.—*continued.*

| Year. | Upper Egypt. | Lower Egypt. Maximum Barrage Gauge in Summer. | Lower Egypt. In Canals. | Lower Egypt. Direct from Rosetta and Damietta Branches. | Lower Egypt. Total. | Total, Upper and Lower Egypt. | Supply available in the Nile in Summer from all Sources. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| 1903 | 120 | 15·50 + Aswan Reservoir | 430 | 40 | 470 | 590 | 550 | Aswan reservoir began working, and Assiut Barrage completed. |
| 1904 | 130 | | 570 | 40 | 510 | 640 | 600 | |
| 1905 | 140 | | 500 | 40 | 540 | 580 | 540 | |
| 1906 | 150 | | 600 | 40 | 640 | 790 | 750 | |
| 1907 | 145 | | 520 | 40 | 560 | 705 | 665 | |
| 1908 | 130 | | 460 | 40 | 500 | 630 | 590 | |
| 1909 | 180 | | 530 | 40 | 570 | 650 | 610 | |
| 1910 | 170 | | 560 | 40 | 600 | 770 | 730 | |
| Mean | 145 | 15·50 | 510 | 40 | 550 | 670 | 630 | |

*Note.*—The supplies utilised differ somewhat from the Government figures, as we do not tie ourselves to rigid dates but consider the periods of real low supply.

Since 1903 the Aswan Reservoir has helped the summer supply of the Nile, while the Assiut Barrage has made the Ibrahimia Canal independent of the fluctuating level of the Nile.

71. **Areas commanded and under Crop.**—The areas commanded have been shown in paragraph 65 to consist of

| | |
|---|---|
| Ibrahimia Canal . . . . . | 922,000 acres. |
| Giza pumps . . . . . . | 42,000 ,, |
| Total, Upper Egypt . | 964,000 ,, |
| Lower Egypt . . | 3,100,000 ,, |
| Egypt . . | 4,064,000 ,, |

In paragraph 70 we have seen that in recent years the Ibrahimia Canal has received 145 cubic metres per second, and if we allow the Giza pumps 15 cubic metres per second in summer, we have a total summer discharge for perennially irrigated Upper Egypt of 160 cubic metres per second. Lower Egypt has received 550 cubic metres per second. The whole perennially irrigated area in Upper Egypt lies in the Middle Egypt belt.

In paragraph 65 we have allowed an acre of summer crop in Middle Egypt to require 30 cubic metres of water per day. In Lower Egypt dry crops require 24, and rice requires 60 cubic metres per day. In Middle

Egypt, therefore, 1 cubic metre per second will suffice for 2880 acres, and in Lower Egypt for 3600 acres of dry crop or 1450 acres of rice. As the rice area is about one-seventh of the total area, the duty of a cubic metre per second of water in Lower Egypt is about 2880 acres in summer (see bottom of Table 185).

The summer supply of Upper Egypt in an ordinary year suffices therefore for (145 × 2880, or) 420,000 acres; and of Lower Egypt for (550 × 2880, or) 1,580,000 acres.

The area actually irrigated in an ordinary year by the perennial canals of Upper Egypt is thus made up:—

| | | |
|---|---|---|
| Assiut Barrage Circle . . . | 50,000 | acres. |
| Fourth Circle . . . . . . | 210,000 | ,, |
| Fayum . . . . . . . | 95,000 | ,, |
| Giza . . . . . . . | 35,000 | ,, |
| Total . . | 390,000 | ,, |

The area actually irrigated in Lower Egypt is—

| | | |
|---|---|---|
| West of the Rosetta branch . . | 330,000 | acres. |
| Between the two branches . . | 670,000 | ,, |
| East of the Damietta branch . . | 680,000 | ,, |
| Total . . | 1,680,000 | ,, |

Since Egypt possesses wide stretches of uncultivated land, we recapitulate here from CHAPTER I., paragraph 13:—

TABLE 187A.—CULTIVABLE AREAS IN ACRES.

| Class of Land. | Upper Egypt. | Lower Egypt. | Egypt. |
|---|---|---|---|
| Area cultivated . . . | 2,251,000 | 3,100,000 | 5,351,000 |
| Area uncultivated . . . | 122,000 | 1,190,000 | 1,312,000 |
| Total . . . | 2,373,000 | 4,290,000 | 6,663,000 |

The irrigation from the canals is supplemented by a large number of pumping stations which take direct from the Nile, from canals and drains, and from wells in the fields. The figures for wells in the fields have been kindly supplied by Mr C. Crawley, Chief of the Technical Service of the Public Works Ministry.

TABLE 188.—WATER-LIFTING ENGINES AND SAKIAS IN THE PERENNIAL TRACTS.

| Locality. | Fixed and Portable Steam and Oil Engines and Pumps. | | | | | | | | | | Sakias. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Main Nile. | | Rosetta Branch. | | Damietta Branch. | | On Canals and Drains. | | Wells in Fields. | | Nile and Branches. | Canals and Drains. | In Fields. |
| | No. | H.P. | No. | H.P. | No. | H.P. | No. | H.P. | No. | I.H.P. | No. | No. | No. |
| *Upper Egypt Inspectorate*— | | | | | | | | | | | | | |
| Fayum Circle | ... | ... | ... | ... | ... | ... | 28 | 260 | 1 | 10 | | | |
| Fourth " | Attributed to basin tracts | | | | ... | ... | 39 | 454 | Basin tracts | | ... | 782 | |
| Barrage " * | 28 | 485 | ... | ... | ... | ... | 6 | 67 | Attributed to basin tracts. | | | | |
| Total | 28 | 485 | ... | ... | ... | ... | 73 | 781 | 1 | 10 | ... | 782 | |
| *Lower Egypt Inspectorate*— | | | | | | | | | | | | | |
| First Circle | ... | ... | ... | ... | 44 | 440 | 745 | 7,450 | 2290 | 23,000 | 252 | 25,830 | 240 |
| Second " | ... | ... | 61 | 795 | 58 | 580 | 1246 | 12,302 | | | 342 | 20,505 | 4560 |
| Third " | ... | ... | 50 | 896 | ... | ... | 614 | 5,602 | | | 65 | 7,838 | 355 |
| Zifta " | ... | ... | ... | ... | 167 | 2220 | 695 | 8,303 | | | 200 | 5,122 | 100 |
| Barrage " † | ... | ... | 8 | 216 | ... | ... | 19 | 382 | Attributed to basin tracts. | | | | |
| Total | ... | ... | 119 | 1907 | 269 | 3220 | 3319 | 34,039 | 2290‡ | 23,000 | 759 | 59,295 | 5255 |

* Cairo engines not included. † The lands attached to this circle are almost entirely in Upper Egypt.

‡ Menufia, 860; Gharbia, 430; Behera, 115; Kaliubia, 355; Sharkia, 270; Dakahlia, 260.

## CHAPTER VII.

## *PERENNIAL IRRIGATION* (2).

72. Perennial Irrigation, Lower Egypt, 1912.—73. Perennial Irrigation, Upper Egypt, 1912.—74. Drainage and Escapes.—75. Engineering Details.—76. Division of Supplies and Rotation.—77. The Ibrahimia Canal.—78. The Fayum.

72. **Perennial Irrigation, Lower Egypt, 1912.**—Lower Egypt is divided into four circles of irrigation. The First Circle has charge of the canals east of the Damietta branch with the exception of the north-west corner. The Second Circle has charge of the canals between the two branches with the exception of the north-east corner. The Zifta Circle takes charge of the canals on both sides of the Damietta branch north of Zifta. The Third Circle has in its charge the canal systems west of the Rosetta branch. The Ismailia, Sharkawia, Basusia, and Rayah Tewfiki Canals take their supplies from the right bank of the Nile above the Delta Barrage. The Rayah Menufia has its head between the two Delta Barrages. From upstream of the Zifta Barrage on the Damietta branch the Mansuria Canal takes off on the right bank and the Rayah Abbas on the left bank. During summer the Damietta branch is closed with a temporary earthen dam upstream of Damietta. The Rayah Behera takes off from the left bank of the Nile upstream of the Delta Barrages. The Rosetta branch is closed with a temporary earthen dam upstream of Rosetta. From the pool above the dam take off the Bahr Saidi and Birimbal Canals on the right bank, while a pumping station at Atfeh on the left bank at the Mahmudia Canal head ensures the supply of Alexandria.

All the canals have regulating heads. The canals taking off from above the Delta Barrages have their beds about 5 or 6 metres below the level of the country, and as they run 2 or 3 metres deep in summer, the water surface is about 3 metres below the level of the country at their heads. As, however, they gain on the country, they give flush irrigation about 30 kilometres below their heads. Well would it have been for Lower Egypt if the canals traversing the rich lands of the southern Delta with their dense fellahin population had continued to be irrigated by lift in summer as they had been for over half a century. Some strong man in the future will reverse the perpetual flush irrigation of to-day and return to the healthier methods of irrigation of the past. These lands to-day with

half their area under cotton do not give so good a yield as they did in the old days of lift irrigation, when one-third the area only was under cotton and the spring level was two metres lower than it is to-day.

Unfortunate as have been the effects of the greatly raised water surface at the Delta Barrage, the excessive raising of the summer level at the Zifta Barrage has been even more serious. Lands which never yielded less than 6 to 8 kantars of cotton per acre now yield only 5, while tens of thousands of acres are maintained in a wet spongy state, and the yellow, sickly-looking Indian corn is a different plant from the dark-green, robust stalks which used to delight the eye fifteen years ago.

We now quote from a lecture delivered by Sir W. Willcocks at a meeting of the Egyptian Institute on the 11th December 1911, and entitled "A Ten Million Kantar Cotton Crop."

"Sir Hanbury Brown, in his book *The Delta Barrage*, notes that the first recorded cotton crop was that of 1820, which produced under 1000 kantars. The next year the figures had increased to 35,000. From 1822 to 1850 the yield varied from 120,000 to 380,000 kantars. In the next decade the figures varied between 480,000 and 590,000.

In 1861 the Delta Barrage began to work, and the yield rose from 720,000 kantars in that year to 2,500,000 kantars in 1876.

In the seven years from 1877 to 1883 the Barrage held up to an average of 12·50 metres on its gauge, and, with an area of some 800,000 acres, the average annual yield was 2,500,000 kantars, or 3 kantars per acre.

In the seven years from 1884 to 1890 the Barrage held up to 13 metres on its gauge, and, with an area of 900,000 acres, the yield was 3,200,000 kantars, or 3·5 kantars per acre.

In the ten years from 1891 to 1900 the Barrage held up to 14 metres on its gauge, and, with an area of 1,100,000 acres, the yield was 5,450,000 kantars, or 5½ kantars per acre. This was the high-water mark of cotton production in Egypt.

In 1901 the Barrage began to hold up to 15·50 metres on its gauge, and during 1901 and 1902 the area rose to 1,250,000 acres, and the annual yield to 6,100,000 kantars. The rate per acre had fallen to 4·9 kantars.

In 1903 the Aswan Reservoir began to be drawn upon, and in the eight years from 1903 to 1910 the area increased from 1,300,000 to 1,600,000 acres. So that with an average acreage of 1,450,000 acres the yield became 6,530,000 kantars; and the rate fell to 4·5 kantars per acre.

The low yield of three kantars per acre previous to 1884, and of 3½ kantars an acre from 1884 to 1890, while the Barrage held up to 13 metres and under on its gauge, was principally due to shortage of water and very poor drainage or no drainage at all.

Even in 1884, when there was practically no cotton worm, the rate of yield was only 4¼ kantars per acre. Large areas of land in the north of the Delta were, moreover, under ratoon cotton, and received no irrigation at all until the flood came in August. Their yield was always very poor.

I have often heard it remarked that no inconsiderable part of the heavy drop from 5½ kantars to 4½ kantars per acre has been due to the large area of

inferior land which has been put under cotton of recent years. What I have seen in the Delta has been exactly the opposite. Formerly immense areas of salted and undrained land were put under cotton and yielded little indeed; but large sections of such lands have been improved out of recognition by the capacious Government drains constructed during the last eight years, and by the really serious reclamation works carried out by certain land companies and large proprietors.

Wherever one moves in the north, one is generally struck by the change for the better. It is not in the poor and salted lands that the depreciation has taken place; it is in the good lands. As a rule the poor lands are better, the rich lands are worse.

In the ten years from 1891 to 1900, when the Delta Barrage held up to 14 metres on its gauge, irrigation in the Delta was at its best. The spring level was not generally too high; the canals were sufficiently deep to carry their summer supplies ordinarily within soil, and to act as drains when they were closed; they had indifferent banks and could not be run at a high level, but they had capacious channels. The drainage of the country was anything but perfect, but the rich lands as a rule needed no drainage. It was in the midst of this prosperity that the idea was conceived of raising the water surface at the Barrage. I quote from the Irrigation Report for 1897: 'It is further intended to raise the gates of the existing Barrage, so that a water level of 15·50 metres may, when necessary, be retained upstream of the structure. Early sowing of the maize crop will be greatly facilitated, and all possible advantage taken of the rising flood.' The second edition of *Egyptian Irrigation* had serious misgivings about the raising of the water surface of the main canals in the middle reaches of the Delta, which this operation entailed.

The level was raised in 1901, and immediately the yield of cotton fell. The fall was aggravated by the way in which the water of the Aswan Reservoir was utilised to meet the persistent demands of the agricultural community. In 1903 the Aswan Reservoir first sent down its quota, and the Irrigation Report for that year tells us what happened: 'Canal rotations were relaxed generally early in July, instead of the middle of August. The prohibition against irrigation of land for the maize sowings was removed one month earlier than the usual date. Rice irrigation was permitted everywhere, and the entire cotton crop was plentifully watered. The maize crop, although affected by the cool weather, was a plentiful one. A large area was planted with cotton, and at one time a record crop appeared probable. There was no shortness of water, but unfortunately the same climatic conditions were reproduced which had reduced the yield for several years in succession.' The report for 1904 carries on the same tale: 'In consequence of the early rise and good supply, the prohibition against the irrigation of land for the early maize sowings was removed on the 15th June. The cotton crop in Lower Egypt must be classed as a comparative failure.' Indeed, if we deduct the Upper Egypt yield, we find that Lower Egypt, with a greatly increased area, actually produced less cotton than it did twelve years before.

The report for 1909 is still more illuminating:—

'The tendency is to hold the reservoir supply later and later every year, so that the mass of the water is employed to augment the early stages of the flood rather than to increase the volume of the river at its lowest. Amongst the various concessions rendered possible by the plentiful water supply, none was more appreciated than the early removal of the prohibition to irrigate the land for maize, which was effected on dates varying from the 15th June to the 1st July. The maize crop

was abundant and the out-turn of good quality. The cotton crop has been the worst for many years, and it is not likely that we shall have much more than five million kantars, or an average of 3·2 kantars per feddan. The quality is unfortunately as bad as the yield.'

Between 1879 and 1884 there was very little water available for irrigation in the months of March and April, as the Barrage gates were not lowered till the gauge fell to 12·50 metres; and, the canals being also full of silt, there was but little water in them till the 15th April, when the sowings began. The consequence was that the clover was cut about three times and allowed to die off, and the worms, over extensive areas, having neither clover nor cotton to feed upon at a fixed period of their existence, died off in numbers. Since 1884 all this has been altered. The clover is irrigated into June, and the worm has been given a convenient bridge.

The green, well-irrigated fields of clover, moreover, interspersed between the cotton fields, have increased the coolness and freshness of the air in the neighbourhood of the cotton plants as compared with the hot, dry atmosphere of the baked and naked clay soil of former days. The worms feed on the clover until the young cotton plants (sown much earlier nowadays) are sufficiently umbrageous to receive them.

If, now, the cotton fields can be kept dry and the plants hard and fibrous, millions of the worms perish. If, however, the plants are soft, and the general atmosphere is damp and humid, the worm finishes his course, and the next brood is a public calamity. Since 1901, and in a much more aggravated form since 1903, everything has been done to make it climatically very favourable for the worm, and it is not to be wondered at that the worm has worked havoc among the cotton fields. The high-level canals have permanently raised the spring level and reduced the volume of soil on which the cotton plant can feed. In addition to raising the spring level, we have brought flood conditions earlier into play than was unavoidably necessary, and have further raised the spring level of July by the soaking irrigation for the sowing of the maize crop. The soaking of large areas at a critical period of the worms' life has produced a further addition to the humidity round every soaked area and aided the cotton worm in its work of destruction. During the last two years the soaking of the soil for the sowing of the maize crop has been theoretically fixed for the 20th July, but while there is abundance of water in the high-level canals and the crops at the tails of the canals are well irrigated, there is a tendency for the prohibition to exist only on paper. Water has not been stored at Aswan so that it may be poured into the sea.

So far we have been dealing with the rich lands situated in the flat terraces representing the basins which were in existence in 1820. Here, the flatness of the country, the great diversity of the physical constituents of the soil, and the multitude of small holdings will always make drains exceedingly costly and exceedingly useless; except partially where we have to do with large properties in single hands, and such properties in these tracts are very rare.

For such lands there are two remedies, and they are real remedies. The first remedy is to deepen the canals to what they were in the old days, and let them irrigate flush only when they are running full. Such canals, when closed, will drain the country, as they formerly did, by direct seepage into their channels, and by means of the deep watercourses which will run back and empty themselves into the canals.

The second remedy is to put off the soaking of the country for the maize crop to such a date that the whole of June and the whole of July will be the hot, dry months

they used to be, and the flood will begin in August at its natural time. A hot, dry soil is no habitation for the worm by day, and a tough fibrous leaf is no food at night.

We have seen how we can fight the worm in June and July; there still remains the clover bridge which, in the eyes of some capable agriculturists, is the most serious matter of all. For the removal of this in the rich southern part of the Delta there is the solution of severe rotations of lift irrigation in April and May, which would very greatly reduce the area under clover in those months, but the fellah must have clover for his cattle and his buffalo. There is, however, no doubt that if clover could be prohibited in the cotton lands after the end of April, the cotton worm bridge would be broken, and the yield of cotton would rise immediately."

Since the above lecture was delivered, both the Agricultural and Irrigation Departments have seriously taken up these questions—Khedivial decrees have been issued making it penal to irrigate clover after the 10th May in all but the rice tracts; and the date of the *Sharaki*, or first heavy irrigation for sowing the maize crop, has been put on to the 1st August if necessary. With these two decrees and with the determined effort made by the Irrigation Department to reduce the quantity of water in the middle belt to a minimum, we should see some appreciable results, especially in these years of consecutive very low flood and consequent low ground water.

The following table is taken from the records of the Irrigation Department:—

TABLE 189.—TABLE SHOWING DATES OF SUMMER ROTATIONS, SHARAKI DECREES, AND PERIODS FOR CALCULATING DUTY SINCE THE REGULATION WAS INSTITUTED AT ASWAN DAM.

(Actual Regulation commenced October 1902.)

| Year. | Summer Rotation. | | Prohibition of Sharaki Decree. | | Period for Calculation of Duty. | | | Critical Level of 15·50 reached U.S. Delta Barrage. |
|---|---|---|---|---|---|---|---|---|
| | Commenced. (1) | Ended. (2) | Enforced. (3) | Removed. (4) | From. (5) | To. (6) | Day. (7) | |
| 1902 | May 19 | July 7 | ... | July 15 | May 19 | July 7 | ... | July 30 |
| 1903 | 15 | 5 | May 26 | 1 | 15 | June 30 | 46 | 3 |
| 1904 | June 1 | Aug. 3–16 | 26 | June 15 | 1 | 30 | 61 | June 22 |
| 1905 | May 1 | 26–Sept. 1 | 15 | July 28 | 1 | July 28 | 88 | Aug. 2 |
| 1906 | 18 | Aug. 20 | 15 | 20 | 18 | 20 | 64 | July 25 |
| 1907 | 15 | 10–14 | 15 | 21–25 | 15 | 21 | 63 | 26 |
| 1908 | Apr. 25 | 8–25 | 12 | 22–27 | 12 | 22 | 72 | 29 |
| 1909 | May 24–28 | July 20–Aug. 15 | 25 | June 20–30 | 25 | June 23 | 30 | June 16, July 16 |
| 1910 | 15 | 15–18 | 18 | July 27 | 15 | July 27 | 74 | 31 |
| 1911 | 1 | 20–25 | 15 | 16–20 | 1 | 20 | 81 | 23 |
| 1912 | Apr. 20 | 16 | 5 | 27 | Apr. 20 | 27 | 99 | 30 |

*N.B.*—The figures given in column (7) show the number of days included between column (1) and column (4). This, however, does not apply to the years 1904 and 1908.

The four following tables show :—

(1) The steady rise of the river in the summer months since 1872, owing to increased regulation at the Delta Barrage.

(2) The behaviour of the river at the Delta Barrage in certain typical years.

(3) Details of the flood in typical high and low floods.

(4) The areas under cotton and the yield per acre from 1896 to 1911. They bear testimony to the steady fall in the yield per acre as the level of the water in the canals in summer has been raised, and with it the ground water.

TABLE 190.—UPSTREAM ROSETTA BARRAGE GAUGES.

(Reduced Levels of Water Surface.)

| Date. | 1872–1887. | 1884–1890. | 1891–1900. | 1901–1902. | 1903–1911. |
|---|---|---|---|---|---|
| January 15 . . | 13·4 | 13·4 | 13·5 | 13·8 | 13·8 |
| 31 . . | 13·1 | 13·2 | 13·4 | 13·6 | 13·9 |
| February 14 . . | 13·0 | 13·4 | 13·5 | 13·9 | 14·5 |
| 28 . . | 12·9 | 13·3 | 13·6 | 14·1 | 14·6 |
| March 15 . . | 12·9 | 13·3 | 13·5 | 14·2 | 14·6 |
| 31 . . | 12·7 | 13·1 | 13·5 | 14·1 | 14·7 |
| April 15 . . | 12·5 | 13·1 | 13·6 | 14·1 | 14·6 |
| 30 . . | 12·3 | 13·0 | 13·6 | 14·0 | 14·6 |
| May 15 . . | 12·3 | 13·0 | 13·6 | 13·8 | 14·5 |
| 31 . . | 12·2 | 13·0 | 13·5 | 13·7 | 14·6 |
| June 15 . . | 12·1 | 12·9 | 13·6 | 13·8 | 14·6 |
| 30 . . | 12·3 | 13·0 | 13·6 | 13·7 | 14·9 |
| July 15 . . | **12·6** | **13·1** | **13·9** | **14·4** | **15·1** |
| 31 . . | 13·7 | 13·5 | 14·4 | 15·5 | 15·5 |
| August 15 . . | 15·8 | 15·8 | 15·9 | 15·6 | 15·8 |
| 31 . . | 16·4 | 16·3 | 16·3 | 16·1 | 16·3 |
| September 15 . . | 16·7 | 16·7 | 16·7 | 16·3 | 16·5 |
| 30 . . | 17·0 | 16·8 | 16·8 | 16·2 | 16·6 |
| October 15 . . | 16·9 | 16·6 | 16·8 | 16·1 | 16·6 |
| 31 . . | 16·2 | 16·1 | 16·6 | 15·8 | 16·4 |
| November 15 . . | 15·0 | 14·7 | 15·3 | 15·6 | 15·7 |
| 30 . . | 14·4 | 14·1 | 14·5 | 14·6 | 15·4 |
| December 15 . . | 14·0 | 13·8 | 14·2 | 14·2 | 15·0 |
| 31 . . | 13·6 | 13·5 | 13·8 | 14·1 | 13·9 |

TABLE 191.—LOW NILES AND HIGH NILES AT THE DELTA BARRAGE GAUGE, ROSETTA BRANCH, UPSTREAM.

(Reduced Levels.)

| Date. | Low Nile Floods. | | | High Nile Floods. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1877. | 1888. | 1899. | 1863. | 1874. | 1878. | 1887. | 1892. | 1894. | |
| Jan. 15 . | 13·0 | 13·6 | 14·0 | 13·3 | 12·6 | 12·5 | 13·2 | 13·3 | 13·2 | |
| 31 . | 12·7 | 13·1 | 13·8 | 13·1 | 12·3 | 12·3 | 13·2 | 13·0 | 13·0 | |
| Feb. 14 . | 12·5 | 13·0 | 13·4 | 12·9 | 11·9 | 12·0 | 13·2 | 13·3 | 13·4 | |
| 28 . | 12·2 | 13·1 | 13·7 | 12·8 | 11·3 | 11·7 | 13·1 | 13·4 | 13·5 | |
| Mar. 15 . | 11·9 | 13·0 | 13·9 | 12·6 | 10·8 | 11·1 | 13·4 | 13·4 | 13·5 | |
| 31 . | 11·6 | 13·0 | 13·7 | 12·4 | 10·6 | 10·8 | 12·9 | 13·7 | 13·5 | |
| April 15 . | 11·0 | 13·0 | 13·7 | 12·1 | 10·5 | 10·6 | 12·6 | 13·7 | 13·5 | |
| 30 . | 10·7 | 13·1 | 14·0 | 11·8 | 10·4 | 10·5 | 12·5 | 13·7 | 13·5 | |
| May 15 . | 10·7 | 13·0 | 14·0 | 11·8 | 10·3 | 10·5 | 12·8 | 13·6 | 13·5 | |
| 31 . | 10·6 | 13·1 | 14·0 | 11·4 | 10·3 | 10·4 | 13·0 | 13·4 | 13·5 | |
| June 15 . | 10·7 | 12·9 | 14·0 | 11·3 | 10·3 | 10·3 | 12·9 | 13·3 | 13·5 | |
| 30 . | 10·9 | 13·0 | 14·0 | 11·4 | 10·7 | 10·2 | 13·0 | 13·3 | 13·7 | |
| July 15 . | 12·0 | 13·1 | 14·3 | 12·1 | 11·8 | 10·4 | 13·1 | 14·0 | 13·9 | |
| 31 . | 13·5 | 13·1 | 14·3 | 14·6 | 13·5 | 11·0 | 14·3 | 14·0 | 14·1 | |
| Aug. 15 . | 14·7 | 15·1 | 15·0 | 16·3 | 16·0 | 15·7 | 16·9 | 15·8 | 16·4 | |
| 31 . | 15·3 | 15·9 | 15·5 | 16·6 | 17·2 | 16·7 | 17·3 | 16·6 | 16·9 | |
| Sept. 15 . | 15·2 | **16·0** | 15·5 | 17·2 | 17·9 | 17·4 | 18·0 | 17·4 | 17·3 | Flood. |
| 30 . | **15·3** | 15·7 | **15·5** | **18·1** | **18·2** | 18·2 | **18·2** | **18·1** | 18·0 | |
| Oct. 15 . | 14·8 | 14·7 | 15·2 | 17·9 | 18·2 | **18·3*** | 17·7 | 18·0 | **18·1** | |
| 31 . | 14·3 | 15·0 | 14·9 | 17·0 | 17·0 | 17·2 | 16·2 | 17·8 | 18·0 | |
| Nov. 15 . | 13·9 | 13·6 | 14·8 | 14·9 | 15·5 | 16·7 | 14·8 | 15·9 | 15·9 | |
| 30 . | 13·6 | 13·3 | 14·7 | 14·2 | 14·6 | 15·1 | 14·3 | 14·7 | 14·7 | |
| Dec. 15 . | 13·2 | 13·1 | 14·4 | 13·9 | 14·0 | 14·5 | 13·9 | 14·2 | 14·3 | |
| 31 . | 12·8 | 13·0 | 14·0 | 13·6 | 13·6 | 14·2 | 13·7 | 13·8 | 14·2 | |

* In 1878 the Nile banks upstream of the Barrage breached, or the gauge would have been higher.

TABLE 192.—UPSTREAM ROSETTA BARRAGE GAUGES.
(Reduced Levels of Low and High Nile Floods.)

| Date. | Low Floods. | | | High Floods. | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1877. | 1888. | 1899. | 1874. | 1878. | 1887. | 1892. | 1894. |
| August 5 | 13·8 | 13·1 | 14·7 | 14·2 | 14·0 | 15·4 | 14·2 | 14·3 |
| 10 | 14·3 | 13·9 | 14·9 | 15·1 | 15·1 | 16·4 | 15·5 | 15·3 |
| 15 | 14·7 | 15·1 | 15·0 | 16·0 | 15·7 | 16·9 | 15·8 | 16·4 |
| 20 | 15·0 | 15·3 | 15·4 | 16·6 | 15·9 | 17·1 | 15·6 | 16·3 |
| 25 | 15·2 | 15·4 | 15·4 | 16·9 | 16·4 | 17·3 | 15·9 | 16·4 |
| 31 | 15·3 | 15·9 | 15·5 | 17·2 | 16·7 | 17·3 | 16·6 | 16·9 |
| September 5 | 15·2 | 15·9 | **15·6** | 17·3 | 16·8 | 17·4 | 16·8 | 17·1 |
| 10 | 15·2 | 15·9 | **15·6** | 17·5 | 16·9 | 17·7 | 17·0 | 17·2 |
| 15 | 15·2 | **16·0** | 15·5 | 17·9 | 17·4 | 18·0 | 17·4 | 17·3 |
| 20 | 15·2 | 15·9 | 15·5 | 18·0 | 17·6 | 18·2 | 17·7 | 17·6 |
| 25 | 15·3 | 15·8 | 15·5 | 18·0 | 18·1 | **18·3** | 17·9 | 17·8 |
| 30 | **15·3** | 15·7 | 15·5 | 18·2 | 18·2 | 18·2 | 18·1 | 18·0 |
| October 5 | 15·3 | 15·4 | 15·4 | 18·3 | 18·3 | 18·1 | **18·2** | 17·9 |
| 10 | 15·0 | 15·0 | 15·3 | **18·4** | **18·4** | 18·0 | 18·2 | 18·0 |
| 15 | 14·8 | 14·7 | 15·2 | 18·2 | 18·3 | 17·7 | 18·0 | 18·1 |
| 20 | 14·6 | 14·5 | 15·1 | 18·0 | 18·0 | 17·4 | 17·9 | 18·1 |
| 25 | 14·4 | 14·2 | 15·0 | 17·4 | 17·5 | 16·9 | 17·8 | **18·2** |
| 31 | 14·3 | 15·0 | 14·9 | 17·0 | 17·2 | 16·2 | 17·8 | 18·0 |
| November 5 | 14·2 | 14·2 | 14·9 | 16·5 | 16·9 | 15·6 | 17·3 | 17·3 |
| 10 | 14·1 | 13·7 | 14·8 | 15·9 | 16·6 | 15·1 | 16·6 | 16·7 |

TABLE 193.—COTTON STATISTICS, LOWER EGYPT.

| Year. | Area in acres. | Yield in kantars. | Kantars per acre. |
|---|---|---|---|
| 1896 | 970,000 | 5,440,000 | 5·6 |
| 1897 | 1,030,000 | 6,070,000 | 5·9 |
| 1898 | 1,030,000 | 5,240,000 | 5·1 |
| 1899 | 1,060,000 | 6,100,000 | 5·7 |
| 1900 | 1,140,000 | 5,070,000 | 4·4 |
| 1901 | 1,140,000 | 5,940,000 | 5·2 |
| 1902 | 1,170,000 | 5,370,000 | 4·6 |
| 1903 | 1,170,000 | 5,740,000 | 4·9 |
| 1904 | 1,200,000 | 5,200,000 | 4·3 |
| 1905 | 1,260,000 | 4,960,000 | 3·9 |
| 1906 | 1,260,000 | 5,980,000 | 4·7 |
| 1907 | 1,290,000 | 5,840,000 | 4·5 |
| 1908 | 1,300,000 | 5,500,000 | 4·2 |
| 1909 | 1,330,000 | 3,908,000 | 2·9 |
| 1910 | 1,320,000 | 6,049,000 | 4·6 |
| 1911 | 1,350,000 | 5,906,000 | 4·4 |
| 1912 | 1,350,000 | | |

The following interesting table was prepared by Mr W. R. Williams, Inspector-General of Irrigation of Lower Egypt, and was published in the Irrigation Report for 1909:—

TABLE 194.—AREA UNDER COTTON AND TOTAL PRODUCTION, AND DATA REGARDING SUMMER SUPPLY AND NATURE OF FLOOD.

| Season. | Cotton-growing Area. | Total Crop. | Yield per acre. | Nature of Summer Supply. | Duty of Water in Lower Egypt. | Approximate Date of River attaining R.L. 15·50 Upstream of Barrage. | Nature of Flood Supply. | Date of Removal of Sharaki Decree. |
|---|---|---|---|---|---|---|---|---|
| | acres. | kantars. | kantars. | | Metres cube. | | | |
| 1895 | 977,735 | 5,256,128 | 5·38 | Very good. | ... | August 5 | Rather late and high. | No Sharaki prohibition. |
| 1896 | 1,050,747 | 5,879,479 | 5·60 | Favourable. | 26·00 | 15 | Late and rather high. | |
| 1897 | 1,128,804 | 6,543,628 | 5·80 | About average. | 25·64 | 16 | Late and poor. | |
| 1898 | 1,121,261 | 5,588,816 | 4·98 | Below average. | 24·88 | 12 | Late and high. | |
| 1899 | 1,153,306 | 6,509,645 | 5·64 | Good. | 26·25 | 31 | Very late and worst recorded. | |
| 1900 | 1,230,320 | 5,435,488 | 4·42 | Worst on record. | 22·71 | July 30 | Fairly early and poor. | July 15 |
| 1901 | 1,249,884 | 6,369,911 | 5·10 | Below average. | 24·60 | 22 | Early and poor. | 15 |
| 1902 | 1,275,680 | 5,838,790 | 4·58 | Well below average. | 24·42 | 30 | Fairly early and poor. | 15 |
| 1903 | 1,332,510 | 6,508,947 | 4·88 | About average. | 25·90 | 3 | Very early arrival, but did not rise quickly: was a poor flood. | 1 |
| 1904 | 1,436,708 | 6,313,370 | 4·39 | Exceptionally good. | 34·00 | June 22 | But did not rise much till towards end of July and was a low flood. | June 15 |
| 1905 | 1,566,601 | 5,958,883 | 3·80 | Average. | 25·75 | August 2 | Arrival normal, but low. | July 28 |
| 1906 | 1,506,290 | 6,949,383 | 4·61 | Exceptionally good. | 32·50 | July 25 | Fairly early and nearly average flood. | 20 |
| 1907 | 1,603,224 | 7,234,669 | 4·51 | Very good. | 28·40 | 26 | Early and low. | 23 |
| 1908 | 1,640,415 | 6,751,133 | 4·12 | Below average. | 24·80 | 29 | Rather late and high. | 25 |
| 1909 | 1,600,000 | 5,000,772 | 3·13 | Very good. | 28·36 | 16 | Early and rather high. | June 30 |

The following figures from a paper by Mr Lucas are instructive. They give the mean minimum level of ground water recorded at five wells in Cairo. This is the only continuous series of measurements of the level of ground water that we have. They show conclusively how the raising of the summer level at the Barrage, recorded in Table 190, has raised the minimum water level in the Cairo wells. In connection with this subject, see pages 32, 86, 99, 341, and 415.

TABLE 194A.—RISE OF GROUND WATER AT CAIRO.

| | | | | | |
|---|---|---|---|---|---|
| 1894 | 14·60 metres | 1900 | 14·56 metres | 1906 | 15·74 metres |
| 1895 | 14·95 „ | 1901 | 14·88 „ | 1907 | 15·76 „ |
| 1896 | 14·76 „ | 1902 | 14·79 „ | 1908 | 15·72 „ |
| 1897 | 14·78 „ | 1903 | 15·08 „ | 1909 | 16·12 „ |
| 1898 | 14·61 „ | 1904 | 15·40 „ | 1910 | |
| 1899 | 15·01 „ | 1905 | 15·77 „ | 1911 | |

73. **Perennial Irrigation, Upper Egypt, 1912.** — The Assiut Barrage Circle, in addition to the basin tracts around Assiut, has charge of the perennial irrigation of the Assiut Province. The Fourth Circle takes charge of the perennial irrigation of Minia and Beni Suef and the small basins near the desert. The Fayum Circle has the Fayum Province; while the Delta Barrage Circle has charge of the perennial irrigation of the Giza Province: that on the west depending on the Ibrahimia, and that east of the Nile on two pumps lifting water direct from the Nile. The two pumping stations are at Korimat and Elessi. The former can lift 8·50 cubic metres per second, and the latter 6·25. Both pumps are by Sulzer. The Ibrahimia Canal takes off from above the Assiut Barrage, and at its 60th kilometre sends off the Yusufi Canal, which irrigates a small area on its banks by pumps, but is the source of supply to the Fayum. The principal summer crops are cotton, maize, and sugar on a small scale. The seasons are practically the same as in Lower Egypt.

We now give an abstract from a note on the converted basins kindly written by Mr J. B. Ireland.

"The type sections for the Canals were based on the quantity of water required for the perennial irrigation of an acre of land in an agricultural year as shown in the following table:—

[TABLE

TABLE 195.—QUANTITY OF WATER REQUIRED FOR MIDDLE EGYPT.

| Season and Crops. | Number of Waterings. | Duration of each Watering in days. | Total Duration in days | Depth of Water in each Watering. | Quantity of Water necessary for each Watering per acre. | Total Quantity of Water per acre. | Grand Total Quantity of Water per acre. | Quantity of Water required per diem per acre. |
|---|---|---|---|---|---|---|---|---|
| | | | | centi-metres. | cubic metres. | cubic metres. | cubic metres. | cubic metres. |
| *Summer* (Cotton and Sugar-cane, etc.)— | | | | | | | | |
| Before sowing on Mar. 1 . | 1 | 15 | 15 | 11·5 | 483 | 483 | 4487 | 32·20 |
| First watering on Mar. 16 . | 1 | 15 | 15 | $8\frac{2}{3}$ | 364 | 364 | | 24·26 |
| April 1 to 14 . . . | ... | ... | ... | ... | ... | ... | | |
| April 15 to Nov. 10 . | 10 | 21 | 210 | $8\frac{2}{3}$ | 364 | 3640 | | 17·33 |
| *Flood* (Maize)— | | | | | | | | |
| Sharaki irrigation, July 20 . | 1 | 20 | 20 | 15 | 630 | 630 | 3178 | 31·50 |
| Subsequent waterings from Aug. 11 to Dec. 23 . | 7 | 15 | 105 | $8\frac{2}{3}$ | 364 | 2548 | | 24·26 |
| *Winter* (Wheat, Beans, Barley, Clover, etc.)— | | | | | | | | |
| First watering, Dec. 1 . | 1 | 15 | 15 | 10 | 420 | 420 | 1680 | 28·00 |
| Dec. 16 to Jan. 15, general closure for canal clearance . . . | ... | ... | ... | ... | ... | ... | | |
| Subsequent waterings from Jan. 16 to April 18 . | 3 | 31 | 93 | 10 | 420 | 1260 | | 13·55 |

The quantity of water required per acre = number of waterings × duration of each × depth in metres × 4200·83 square metres.

According to the general custom, 40 per cent. of the gross area of summer crops are grown, 60 per cent. of flood and 60 per cent. of winter, and on this basis, with the use of the preceding table, the duty of water per acre in different seasons is arrived at.

TABLE 196.—QUANTITY OF WATER REQUIRED FOR MIDDLE EGYPT.

| | Percentage of Area under Crops. | | | Extra for Clover Crop. | Quantity of Water required per diem. Cubic metres. |
|---|---|---|---|---|---|
| | Winter. | Summer. | Flood. | | |
| Mar. 1 to 15 . . | 60 | 40 | 0 | 0 | ·40 × 32·2 + 0·60 × 13·55 = 21·01 |
| ,, 16 to 31 . . | 60 | 40 | 0 | 0 | ·40 × 24·26 + 0·60 × 13·55 = 17·83 |
| April 1 to 14 . . | 60 | 0 | 0 | 0 | 0·60 × 13·55 = 8·13 |
| ,, 15 to July 20 . | 0 | 40 | 0 | 1·3 | ·40 × 17·33 + 1·3 = 8·23 |
| July 21 to Aug. 10 . | 0 | 40 | 60 | 0 | ·40 × 17·33 + 0·60 × 31·5 = 25·83 |
| Aug. 11 to Nov. 10 . | 0 | 40 | 60 | 0 | 0·40 × 17·33 + 0·60 × 24·26 = 24·26 |
| Nov. 11 to 23 . . | 0 | 0 | 60 | 0 | 0·60 × 24·26 = 14·55 |
| ,, 24 to 31 . . | 0 | 0 | 0 | 0 | |
| Dec. 1 to 15 . . | 60 | 0 | 0 | 5·42* | ·60 × 28 + 5·42 = 22·22 |
| ,, 15 to Jan. 15 . | 0 | 0 | 0 | 0 | |
| Jan. 16 to Feb. 28 . | 60 | 0 | 0 | 1·87 | ·60 × 13·55 + 1·87 = 10·00 |

* Clover is sown in standing cotton and requires a winter watering of 13·55 cubic metres per acre; the summer crop extends over 40 per cent. of the gross area; therefore, 0·40 × 13·55 = 5·42.

From the above the heaviest demands for water occur when sharaki is irrigated: *i.e.* 25·83 cubic metres per acre of gross areas in July to August, add 5 per cent. for seepage and evaporation, we obtain 27·12 cubic metres which the distributary canals will have to carry.

The branch canals were allowed an extra $7\frac{1}{2}$ per cent. = 27·77, and the main canals 10 per cent. = 28·42. Round figures, a little higher, to cover domestic purposes were adopted, namely:—

| | | |
|---|---|---|
| 27·5 | cubic metres | for distributary canals. |
| 28·75 | ,, | for branch canals. |
| 30·00 | ,, | for main canals. |

The canals were designed as per section:

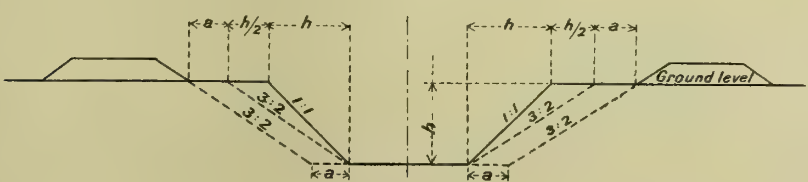



FIG. 29.

*Main Canals and Branch.*—Side slopes 1/1; berm is equal to the constant ($a$ = 1·00) plus $\frac{h}{2}$.

*Distributary Canal.*—Side slopes 3/2; berm $a$ is a constant equal to 0·5 where the bed width is under 1·00 and $a$ = 1·00 where bed width is over 1·00.

The bank level varies between 0·75 and 1·50 above high flood level, and the width, according to the following scale:—

| | | | |
|---|---|---|---|
| Bed width above | 10 metres | . Bank width | 5·00 |
| ,, | between 9 and 7 ,, | . ,, | 4·00 |
| ,, | ,, 7 ,, 5 ,, | . ,, | 3·00 |
| ,, | ,, 5 ,, 4 ,, | . ,, | 2·50 |
| ,, | ,, 4 ,, 3 ,, | . ,, | 2·00 |
| ,, | ,, 3 ,, 1 ,, | . ,, | 1·50 |
| ,, | below 1·00 ,, | . ,, | 1·25 |

A line approximately parallel to land level on the longitudinal section, and averaging 25 centimetres above it, was fixed for maximum water level, and generally the same slope was given to banks and bed.

The three main canals serving the old and new perennial areas are the Ibrahimia and Deirutia downstream of the Deirut regulator, and the Giza Canal taking off from the Bahr Yusuf near Lahun.

The perennial area commanded by the Ibrahimia Canal below Deirut before remodelling was 252,000 * acres, giving approximately 96,000 acres cultivated in summer (*Administration Report*, 1901, page 99): it now serves 514,662 acres; its tail was formerly at Ashmant, but now extends to Ayat—a total of 318 kilometres. The section below Deirut in flood gives high water R.L. 45·30, bed level 41·25 R.L., bed width 49·00 metres, velocity ·95, bed and water slope 0·066, and a discharge of 204 cubic metres per second. The duty in flood is therefore 2500 acres per cubic metre per second.

The Deirutia Canal commands 76,663 acres, of which 58,085 acres are newly converted.

The Giza Canal commands 83,567 acres, all of which are newly converted. Of the old basins on left of Giza Canal the following areas are left under the basin system:—

| | |
|---|---|
| Hager Koshesha | 1,715 |
| Rikka | 3,455 |
| Moarka | 1,946 |
| Tahma | 4,713 |
| Dahshur | 6,386 |
| Sakkara | 4,406 |
| Shabramant | 4,131 |
| Manshia | 4,362 |
| Iswid | 22,098 |
| | 53,212 |

For the filling during flood of the above area of basins two sources have been provided:—

1. From the Bahr Yusuf above Lahun, known as the Hager Koshesha Canal.
2. The Girza Canal taking from the Nile north of Rikka Railway Station.

The old Lebeini channel is used to convey the water from basin to basin.

* See middle of page 389.

The Girza Canal supplies half of the area, namely 26,606 acres; and a pipe syphon, consisting of five pipes of 3·00 metres diameter each, passes the water under the Ibrahimia Canal, the discharge required being 30·8 cubic metres per second, which allows 100 cubic metres per acre per day with full inundation in forty days.

For the discharge of these basins into the Rayah Behera and thence into the Nile a superpassage at Nikla was made across the Moheit drain. During the emptying of the basins the Moheit drain syphons under the basin water, but for the remaining eleven months of the year the drain syphon is not used and the drain water flows in its natural bed, thus allowing for the passage of dredgers in the drain.

It was estimated that a layer of water 0·0019 metre thick is absorbed by the soil in twenty-four hours and that an acre requires a run-off of 4200 square metres × 0·0019 metre = 8 cubic metres per acre per day. The drain sections were designed in the same form as the main and branch canals with side slopes $\frac{1}{1}$. H.F.L. was fixed at 0·50 below natural ground level.

The Main Moheit drain is the main drainage channel for the whole area in the Assiut, Minia, Beni Suef, and Giza Provinces, included between the Bahr Yusuf and Ibrahimia Canal in the three former provinces and between the area left under the basin system and the Giza Canal in the latter province. In summer and winter it discharges by cross cuts into the Nile at Etsa, Sharawa, Koshesha, Ayat, and Abu el Nimros, into the Yusufi at Abu Rahib and Mazura, and the Rayah Behera north of Khatatba.

During flood half of the discharge at Etsa is lifted with pumps into the Nile at Etsa, and opposite Feshn half is escaped into the Bahr Yusuf below Mazura regulator. The balance or run-off from 295,388 acres is all discharged for the present into the Rayah Behera north of Khatatba.

The Etsa pumping station consists of four 40-inch centrifugal pumps capable of discharging 8 cubic metres per second on a lift of 3 metres : there are four vertical direct-acting compound engines + 6 boilers with a working pressure of 125 lbs. per square inch, erected by Easton & Anderson, Erith, Kent.

The Moheit drain is carried across Magrur Koshesha (now used as flood escape channel for the basins west of Bahr Yusuf) in a W.I. pipe syphon consisting of five pipes of two metres diameter each.

During flood the Bahr Yusuf at Lahun has to serve the Fayum Province, the Giza perennial area and half of the Giza basins, and to supplement its supply the Bahabshin Nili Canal has been extended through the Bahabshin basin to the Yusufi, and so the Yusufi obtains red water direct from the Nile.

The total area occupied by canals and drains is $3\frac{1}{2}$ per cent. of the converted area. Of this 2 per cent. is occupied by canals, and $1\frac{1}{2}$ per cent. by drains; 2284 kilometres of the former were made and 1744 of the latter.

The total cost of the conversion of the 405,220 acres was £5,199,210, or £12·83 per acre. The old perennial tract has, however, received benefit, for before the conversion works were undertaken no drainage in flood existed and the Main Moheit drain now ensures good drainage for the whole tract.

Of the 405,220 acres converted, all this area receives free flow irrigation, with the exception of 15,000 acres situated below the Deirut regulators which obtain lift irrigation in summer.

An extra land tax for the converted area of £·50 is levied over all lands obtaining free flow irrigation and has been collected as follows: 1st year, £·20; 2nd year, £·30; 3rd year, £·40; and 4th year, £·50.

For the lands irrigated by lift £·30 extra is levied and collected after three years."

TABLE 197.—COTTON STATISTICS, UPPER EGYPT.

| Year. | Area in acres. | Yield in kantars. | Kantars per acre. |
|---|---|---|---|
| 1896 | 80,000 | 400,000 | 5·0 |
| 1897 | 100,000 | 470,000 | 4·7 |
| 1898 | 90,000 | 350,000 | 3·9 |
| 1899 | 90,000 | 410,000 | 4·5 |
| 1900 | 90,000 | 370,000 | 4·1 |
| 1901 | 110,000 | 430,000 | 3·1 |
| 1902 | 110,000 | 470,000 | 4·3 |
| 1903 | 160,000 | 770,000 | 4·8 |
| 1904 | 240,000 | 1,110,000 | 4·6 |
| 1905 | 310,000 | 1,000,000 | 3·2 |
| 1906 | 250,000 | 970,000 | 3·9 |
| 1907 | 310,000 | 1,390,000 | 4·5 |
| 1908 | 340,000 | 1,250,000 | 3·7 |
| 1909 | 270,000 | 1,092,000 | 4·0 |
| 1910 | 320,000 | 1,521,000 | 4·7 |
| 1911 | 360,000 | 1,514,000 | 4·2 |
| 1912 | 370,000 | | |

74. **Drainage and Escapes.**—This question has passed through many phases since 1883. The first edition of this work was written in the early years of the Occupation, when some of the canals had no regulating works on the Nile, many were veritable rivers, and when no improvements of any kind could be undertaken until the discharges were controlled. The canals of the Delta proper between the two branches discharged in flood 1100 cubic metres per second, utilised 500, and poured 600 cubic metres per second into the escapes, flooding the whole country. The Barrage was holding up to R.L. 13·00 metres in summer, and the canals were very deep and very unmanageable. Everything then said applied to a state of affairs unknown to-day. In 1890 the Barrage held up to R.L. 14·00 metres, and a great change took place. Colonel Ross, Inspector-General of Irrigation, was for reducing discharges, like the rest of us, while it was a question of reducing the discharges of the canals so that, in the interests of irrigation, they might discharge freely into the escapes without swamping them; but when some engineers kept on reducing the canals in the interests of drainage alone, and began depriving the fields of the rich red water of the flood, he strongly deprecated the action and predicted a red-water famine as recorded in CHAPTER VIII.

The second edition was written in 1897–98, and took up Colonel Ross's position. It was shown what would happen if the suicidal policy of reducing the canals in the interests of the drains alone were continued. CHAPTER VIII. is devoted to the subject and brings the history down to our day.

All irrigation canals need escapes to carry off their excess supplies, and drains to carry off the excess waters of the irrigated fields. The drainage water is subdivided into surface water, and infiltration water which has soaked through the soil. In really scientific irrigation and drainage all these three waters are treated separately. In Egypt the escape water and drainage water have to be carried in one and the same channel. The escape water always enters by gravitation, the surface drains by gravitation as a rule, and the infiltration water has as a rule to be pumped. If now the country were divided into zones, and the escapes and surface drains allowed to flow freely by gravitation and the infiltration water pumped, we should have a plentiful supply of rich red water everywhere, and deep drainage at a minimum of cost and minimum of worry. If, on the contrary, pumps were put up at the tails of the main escape drains and everything pumped, we should have expensive pumping, very expensive deep drains, and a forced reduction of the escape water so that the pumps might not be drowned out. The two systems have been thus compared:—

"In three-quarters of the Delta the water which flows over the surface of the ground can enter the drains without pumping, and needs no pumping. All the canals and watercourses can do so likewise, and need no pumping. All that really requires to be pumped is the infiltration water off three-quarters of the land and the whole of the surface water and infiltration water off one-quarter of the land. With the ordinary system of drainage two-thirds of the water needs no pumping and one-third does. The surface water, when it needs pumping, needs light pumping, and the infiltration water needs deep pumping, generally over 2½ metres in depth. Practical engineers may be permitted to differ from those who assert that it is cheaper to lift the whole of the water at one pump than to lift one-third at many pumps; that it is cheaper, moreover, to dig and maintain thousands of kilometres of drains, with their water surface everywhere 1·50 metres below the surface, than just below the surface; and that to keep this water surface everywhere 1·50 metres below the surface is not an infinitely more difficult task than looking after a few hundreds of pumps.

But what shall we say when we have in the field to-day the Mosséri system of drainage, the most ingenious and the most practical system the world has ever seen? With this system we need only to lift one-sixth of the whole water, and get what none of the other systems have—permanency. Just as Mr Lang-Anderson is the author of the system of washing by infiltration, to Mr Mosséri is due the credit of having brought this system to its just conclusion. You enjoy all the benefits of deep infiltration drainage and all the benefits of surface washing with the water leaving its rich deposit on the land. There is no fatigue of the land owing to lack

of red water; and there is no going back once you have reclaimed owing to the drains being choked.

But not only does the tail pump scheme contemplate lifting from three to six times as much water as need be lifted; it only gives a theoretical depth of water of 1·50 metres at the drain, instead of 2·50 metres and more, which the zone system would give, and which is essential everywhere outside of the very low lands where the beds of the drains are not in salted mud, but in muddy salt, and where weeds are scarce. Those who know what weeds in drains are know that they will never allow the water to be kept permanently at 1·50 metres below the surface, except at a cost excessive even for the Egyptian Treasury.

The question of red water remains. A field of rice gets very nearly as much red water and as much deposit as a first-class basin. A field of maize, with its sharaki irrigation after 1st August, gets half the deposit of a first-class basin. Ordinary land under cotton gets very little red water, and that is partly why cotton is ordinarily so fatiguing; but where a field has good surface drainage one can pass over the land as much water as would leave half the deposit of a first-class basin, letting it then flow away into the drain. Now, red water contains not only chemicals, but sand, bacterial life, and food for bacteria in the soil. Of the four the sand is not the least useful. Chemical manures without red water are a gummy substitute; they bind where red water loosens."

The above may stand as a preface to CHAPTER VIII.

75. **Engineering Details.**—CHAPTER X. is devoted to engineering details.

The protection of the Nile banks during flood is left to the corvée or forced labour of the peasantry. This whole question is very fully treated in CHAPTER XV.

The following table gives the lengths of canals and drains in detail for each circle of Lower Egypt.

TABLE 198.—LENGTHS OF THE CANAL AND DRAINAGE SYSTEMS OF LOWER EGYPT (in kilometres).

| Circle. | Canals. | | | | Drains. | | | |
|---|---|---|---|---|---|---|---|---|
| | Bed-width at Head. | | | Total. | Bed-width at Tail. | | | Total. |
| | Above 12 metres. | Between 6 and 12 metres. | Below 6 metres. | | Above 8 metres. | Between 4 and 8 metres. | Below 4 metres. | |
| First Circle | 360 | 313 | 2614 | 3287 | 319 | 165 | 501 | 985 |
| Second Circle | 482 | 520 | 1908 | 2910 | 151 | 91 | 269 | 511 |
| Third Circle | 258 | 325 | 668 | 1251 | 147 | 148 | 367 | 662 |
| Zifta Circle | 481 | 315 | 984 | 1780 | 414 | 221 | 593 | 1228 |
| Total, Lower Egypt | 1581 | 1518 | 6174 | 9228 | 1031 | 625 | 1730 | 3386 |

The annual maintenance charges for *Lower Egypt* may be taken as follows:—

| | |
|---|---|
| Flood protection and river training | £36,000 |
| Repairs of regulators, etc. | 36,000 |
| Canal clearances by hand | 115,000 |
| " " dredgers | 13,000 |
| Drain " hand | 27,000 |
| " " dredgers | 15,000 |
| Canal remodellings | 24,000 |
| Stone protection of channel | 13,000 |
| Land | 11,000 |
| Petty staff | 12,000 |
| Weed clearances | 3,000 |
| Miscellaneous works on canals | 8,000 |
| Establishment and general | 26,000 |
| Agricultural roads | 9,000 |
| Barrages and pumping stations | 40,000 |
| | £388,000 |

As the area cultivated is 3,100,000 acres, this means that the maintenance charges amount to 12½ piastres per acre, or 2s. 6d. per acre.

If we calculate approximately the original cost of the Barrages at £4,000,000, of the canals at £6,600,000, of the masonry works at £2,200,000, of the Nile banks at £1,500,000, and the drains at £1,400,000, we arrive at a total of £15,700,000 for 3,100,000 acres, or £5·0 per acre.

The above is from the second edition.

The flush irrigation in Lower Egypt is supplemented by

| | | |
|---|---|---|
| On the Nile and on canals. | 388 pumping engines on the Nile, representing | 4127 H.P. |
| | 3319 " " canals, " | 34,039 H.P. |
| | 60,054 sakias. | |
| On wells in the fields. | 2290 oil engines, representing 23,000 I.H.P., and | |
| | 5255 sakias. | |

The annual maintenance charges for perennial irrigation in *Upper Egypt* are approximately as follows:—

| | |
|---|---|
| Repairs and maintenance | £150,000 |
| Establishment classified | 18,000 |
| " unclassified | 18,000 |
| Travelling allowance, etc. | 7,000 |
| Remodelling and new works | 3,000 |
| Total | £196,000 |

As the area under perennial irrigation is about 964,000 acres and the maintenance charges £196,000, the maintenance per acre is twenty piastres, or four shillings per acre.

Flush irrigation in Upper Egypt is supplemented by

28 pumping engines on the Nile, representing 485 H.P.
73 „ „ on the canals, representing 781 H.P.
782 sakias.

The number of different classes of works and the kilometres of canals and drains is given in the following table:—

TABLE 199.—DETAILS OF PERENNIAL CANALS, DRAINS, BANKS, AND WORKS.

*Upper Egypt*—996,000 acres.

| Class of Work. | Fayum Circle. | Assiut Barrage Circle. | Fourth Circle. | Barrage Circle. | Total. |
|---|---|---|---|---|---|
| Nile banks . . kilometres | 5 | ... | 315 | 223 | 543 |
| Canals . . . . „ | 1567 | 634 | 2642 | 889 | 5732 |
| Drains or escapes . „ | 661 | 148 | 1774 | 450 | 3033 |
| Regulators and escape heads . | 275 | 130 | 380 | 260 | 1045 |
| Aqueducts and syphons . . | 35 | 5 | 74 | 50 | 164 |

*Lower Egypt*—3,100,000 acres.

| Class of Work. | First Circle. | Second Circle. | Third Circle. | Zifta Circle. | Total. |
|---|---|---|---|---|---|
| Nile banks . . kilometres | 116 | 316 | 185 | 284 | 901 |
| Canals . . . . „ | 3287 | 2910 | 1251 | 1780 | 9228 |
| Drains and escapes . „ | 985 | 511 | 662 | 1228 | 3386 |
| Regulator and escape heads . | 552 | 417 | 144 | 217 | 1330 |
| Aqueducts and syphons . . | 22 | 46 | 47 | 43 | 158 |

For the total perennial area of *Egypt* of 4,100,000 acres there are in use

| | | |
|---|---|---|
| Nile banks . . . . . . . . . | 1,440 | kilometres. |
| Canals . . . . . . . . . | 14,960 | „ |
| Escapes and drains . . . . . . | 6,420 | „ |
| Regulator and escape heads . . . . | 2,370 | |
| Aqueducts and syphons . . . . . | 320 | |

76. **Division of Supplies and Rotations.**—We give an account of these operations from the reports of the irrigation officers themselves. The first quotation is from the report for 1910 of Mr John Langley, Inspector-General of Upper Egypt, and the second from that of Mr W. R. Williams, Inspector-General of Irrigation for Lower Egypt.

"UPPER EGYPT.

The distribution of water between Upper and Lower Egypt was based on the Finance Ministry areas of summer crops for the preceding year.

As the proportion worked out practically the same as in 1909, no change was made in the arrangement, so the Ibrahimia Canal discharge = 28 per cent. of Delta discharge + 12 cubic metres per second.

The result of the summer distribution in metres per second in the Ibrahimia Canal is as follows :—

| Month. | Actual Mean Discharge. | Ibrahimia. Correct Share. | Difference + | Difference – |
|---|---|---|---|---|
| April . . | 199·6 | 176·0 | 23·6 | |
| May . . | 152·8 | 145·7 | 7·1 | |
| June . . | 157·6 | 152·6 | 5·0 | |

This shows that the distribution was very evenly arranged in May and June, though Upper Egypt got a slight excess supply during April. This may be due to the fact that strict distribution did not begin till about the middle of the month.

In the past two years' reports I have given a table showing a comparison between the quantity of water passing Aswan and arriving at Assiut and the Delta canals after eight and fourteen days respectively, and for comparison's sake I give a similar table.

TABLE 200.—COMPARATIVE DISCHARGES, ASWAN, IBRAHIMIA, AND DELTA CANALS (cubic metres per second).

| Aswan. | | | Ibrahimia. | | Aswan, less Ibrahimia Discharge. | Delta Canals. | | + | – |
|---|---|---|---|---|---|---|---|---|---|
| Date. | Gauge. | Discharge. | Date. | Discharge. | | Date. | Discharge. | | |
| May 1 | 84·91 | 550 | May 9 | 150 | 400 | May 15 | 440 | 40 | |
| 5 | 84·91 | 550 | 13 | 150 | 400 | 19 | 450 | 50 | |
| 9 | 84·90 | 550 | 17 | 140 | 410 | 23 | 490 | 90 | |
| 15 | 84·90 | 550 | 21 | 140 | 410 | 27 | 460 | 50 | |
| 21 | 85·00 | 610 | 29 | 150 | 460 | June 4 | 460 | | |
| 26 | 85·00 | 610 | June 3 | 160 | 450 | 9 | 470 | 20 | |
| 29 | 85·10 | 660 | 6 | 160 | 500 | 12 | 510 | 10 | |
| June 2 | 85·20 | 700 | 14 | 160 | 540 | 20 | 520 | ... | 20 |
| 10 | 85·30 | 750 | 18 | 160 | 590 | 24 | 530 | ... | 60 |
| 14 | 85·30 | 750 | 22 | 160 | 590 | 28 | 580 | ... | 10 |
| 18 | 85·40 | 800 | 26 | 160 | 640 | July 2 | 580 | ... | 60 |
| 22 | 85·49 | 820 | 30 | 170 | 650 | 6 | 630 | ... | 20 |
| 26 | 85·60 | 900 | July 4 | 180 | 720 | 10 | 640 | ... | 80 |
| 30 | 85·80 | 1000 | 8 | 190 | 810 | 14 | 700 | ... | 110 |

It will be seen that the loss became apparent soon after the supply was augmented from the reservoir on a rising gauge when the channel of the river absorbed a considerable quantity of water.*

* This subject will be returned to in CHAPTER XIII., where we give independent figures.

The following table gives the discharge entering the Yusufi at Deirut and arriving at Lahun, which shows a pretty constant gain *en route.*

TABLE 201.—DISCHARGES OF BAHR YUSUFI (in cubic metres per second).

| Downstream Deirut. | | Upstream Lahun. | | Gain *en route.* | Loss *en route.* |
|---|---|---|---|---|---|
| Date. | Discharge. | Date. | Discharge. | | |
| April 3 | 65 | | | | |
| 9 | 63 | April 17 | 87 | 14 | |
| 15 | 62 | | | | |
| 21 | 61 | | | | |
| 27 | 49 | May 2 | 62 | 13 | |
| May 3 | 62 | 9 | 57 | ... | 5 |
| 10 | 53 | 16 | 55 | 2 | |
| 15 | 45 | 23 | 55 | 9 | |
| 22 | 50 | 30 | 52 | 2 | |
| 27 | 41 | June 6 | 50 | 9 | |
| June 2 | 41 | 13 | 50 | 9 | |
| 14 | 47 | 20 | 50 | 3 | |
| 20 | 45 | 27 | 50 | 5 | |
| 26 | 47 | | | | |
| July 2 | 50 | July 4 | 50 | | |
| 8 | 53 | 11 | 55 | 2 | |
| 14 | 58 | 18 | 55 | ... | 3 |
| 20 | 60 | 25 | 60 | | |
| 26 | 69 | Aug. 1 | 62 | ... | 7 |

The annual winter closure was carried out as usual as follows:—

| Circle. | Town. | From | To | Duration. |
|---|---|---|---|---|
| Fourth Circle | Beni Suef | Dec. 26 | Feb. 10 | 46 days. |
| | Minia | Jan. 6 | 10 | 36 ,, |
| Assiut Barrage Circle | Assiut, North | Dec. 25 | Jan. 25 | 30 ,, |
| Fayum Circle | Fayum | Jan. 10 | Feb. 10 | 30 ,, |
| | | 1 | Jan. 20 | 35 ,, |
| | | Feb. 15 | Mar. 1 | |

DISTRIBUTION BETWEEN CIRCLES.

This, as in past years, was arranged by taking the Finance Ministry's figures for the areas under summer crops in each circle ; the summer area on the Giza Canal was estimated by assuming it to be 40 per cent. of the total area served, or 36,430 acres.

The result was as follows :—

| Circle. | Areas in acres. | Proportion per cent. |
|---|---|---|
| Fourth Circle . . . | 225,000* | 55·7 |
| Fayum Circle . . . | 102,000 | 25·3 |
| Assiut Barrage Circle . . | 40,000 | 10·0 |
| Giza Canal . . . . | 36,430 | 9·0 |
| Total . . . | 403,430 | 100·0 |

Proportional distribution was based on the sum of the discharges of the five canals at Deirut, the upstream discharge in the Ibrahimia Canal being considered unreliable owing to the discharge site being affected by the afflux on Deirut regulators.

The distribution between the Fayum Circle and the Giza Canal was carrried out at Lahun, and was obtained, as follows :—

Total area, 138,430 acres.

Fayum share, 73·7 per cent.

Giza Canal share, 26·3 per cent.

of the discharge reaching Lahun.

### ROTATIONS, FOURTH CIRCLE.

Immediately after general closure spring rotations were enforced, consisting of seven days' supply and seven days' closure ; these worked satisfactorily and gave rise to no complaints.

Summer rotations were started on 15th April, consisting of three turns of six days each, so that there were six working days in eighteen.

The water supply was sufficient for all requirements up to 15th May, and no difficulty in distribution was experienced.

After this date the supply of the circle downstream Deirut was considerably reduced. At the request of the acting Inspector, a day of general closure was introduced between each working turn from the 21st May ; I consider that this step is necessary should the gauge downstream Deirut fall below R.L. 44·00 during the month of May.

Second-class rotations, viz., six working days in twenty-one, were enforced from 21st May to 13th August, when flood rotations commenced : they were accepted by all the Provincial Councils, and gave rise to very few complaints.

The internal distribution between the three Chief Engineers' divisions, into which this circle is divided, was based entirely on discharge curves plotted from the results of observations taken during the past three years."

## "Lower Egypt.

### CANAL CLOSURES AND DISTRIBUTION OF SUPPLY DURING THE SPRING.

The usual winter closure for the clearance of channels was in force during slightly varying periods between the end of December and the beginning of February.

* 16,944 acres have been deducted from the total area as having been watered from the Yusufi, Nile, and wells.

In the First Circle the date of the closure was, at the special request of the Provincial Councils of Kaliubia and Sharkia, delayed until the 1st January.

Following the annual closure, water distribution was effected by the usual spring rotations of from five to seven days' high and ten to seven days' low levels, until the enforcement of summer rotations.

DISTRIBUTION OF SUMMER SUPPLY.

The distribution of the summer supply by provinces remained as in former years, namely:—

| | |
|---|---|
| Kaliubia, Sharkia, and Dakahlia . . . . . | 41 per cent |
| Menufia and Gharbia . . . . . . . | 38 ,, |
| Behera and Rayah Behera District . . . . | 21 ,, |

The distribution of the summer supply to the various circles was, as last year, fixed as follows:—

| | | | |
|---|---|---|---|
| First | Circle, | 25 | per cent. of total discharge entering Lower Egypt. |
| Second | ,, | 25½ | ,, ,, ,, ,, |
| Third | ,, | 21 | ,, ,, ,, ,, |
| Zifta | ,, | 28½ | ,, ,, ,, ,, |

SUMMER ROTATIONS.

Summer rotations in the cotton zones, generally of three sections, each with six days' working and twelve days' stopping, or one watering every eighteen days, were enforced from the 15th May.

Summer rotations in the rice zones, generally of two sections, each with four days' working and five days' stopping, or one watering every nine days, were enforced from the same date.

Both classes of rotations were removed between the middle and end of August, and in some outlying tracts the rice rotations were actually carried on into September. This prolongation of the summer rotations, together with the late removal of the Sharaki Decree, had very good results in preventing the cultivators from overwatering their cotton crops.

In the *First Atfeh District* of East Giza rotations were enforced by working the Korimat pumps for nine days and then stopping for a similar period. No difficulties arose with this rotation, owing to the area under cultivation being considerably less than that for which the pumps were designed.

In the *Second Atfeh District* rotations were enforced from the 12th May, and the district divided into three sections. In the first, or upper section, two pumps worked for seven days, then fed the second section for six days, and then the third for five days.

A table showing the precise nature and periods of the summer rotations enforced in each circle is annexed.

TABLE 202.—NATURE AND PERIOD OF SUMMER ROTATIONS ENFORCED IN EACH CIRCLE, 1910.

| Circle. | Districts affected. | Period of Enforcement. | | Nature of Rotations. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Ordinary Crops. | | Rice. | |
| | | From | To | Working. | Stopping. | Working. | Stopping. |
| | | | | Days. | Days. | Days. | Days. |
| First Circle. | Kaliubia, Sharkia, and south-east part of Dakahlia Provinces and part of Ismailia Canal zone. | May 15 | Aug. 15 | 6 | 12 | 4 | 5 |
| Second Circle. | Menufia and north-west of Gharbia Provinces. | May 15 | Aug. 18 | 6 | 12 | 4 | 5 |
| Third Circle. | South Behera Division and Shubrakhit District. | May 15 | July 25 | 6 | 12 | | |
| | | July 26 | Aug. 31 | 8 | 10 | | |
| | | May 13 | July 5 | ... | ... | 4 | 6 |
| | | July 6 | Aug. 31 | ... | ... | 5 | 5 |
| | North Behera Division. | May 13 | July 5 | ... | ... | 4 | 6 |
| | | July 6 | Sept. 17 | ... | ... | 5 | 5 |
| Zifta Circle. | Greater part of Dakahlia and north-east of Gharbia Provinces. | May 15 | June 15 | 6 | 12 | | |
| | | June 14 | July 20 | 6 | 15 | | |
| | | July 21 | Aug. 12 | 6 | 12 | | |
| | | May 15 | June 11 | ... | ... | 4 | |
| | | June 12 | Aug. 12 | ... | ... | 4 | 6" |

We now give a translation of an interesting paper by M. Audebeau Bey, Chief Engineer of the State Domains, on the subdivision of the water supplied by pumps to lands under crop. What he has said would apply equally well to drainage pumps.

"When a large proprietor has a certain number of small pumps to irrigate his property, he is tempted by mechanical engineers, who are thinking only of economies in fuel, grease, repairs, and establishment, to replace them by a single pump. If he makes the change, he seldom fails to regret his decision.

Since the small pumps serve small areas, they have short and small irrigation channels. Big pumps have long and big channels which cause damage by infiltration, especially as they begin as a rule in sandy soil near the canal at their heads.

The economies in fuel and establishment are lost many times over in the inferiority of the crops over large areas of saturated and salted land.

If, as in the example, one big pump replaces four small ones, and cotton is growing in the hatched area, the water running in the channels A B and C D hurts large areas of land not under crop.

By electric transmission, a single installation can work many pumps. I give an example.

In the Domains lands at Santa, we have a small cotton-ginning factory with an engine of 120 to 130 effective h.p. This factory is not worked in winter and summer when we do our pumping. Near it we had seven small pumps. In 1896, afraid of accidents to the electric installation, we unfortunately reduced the seven

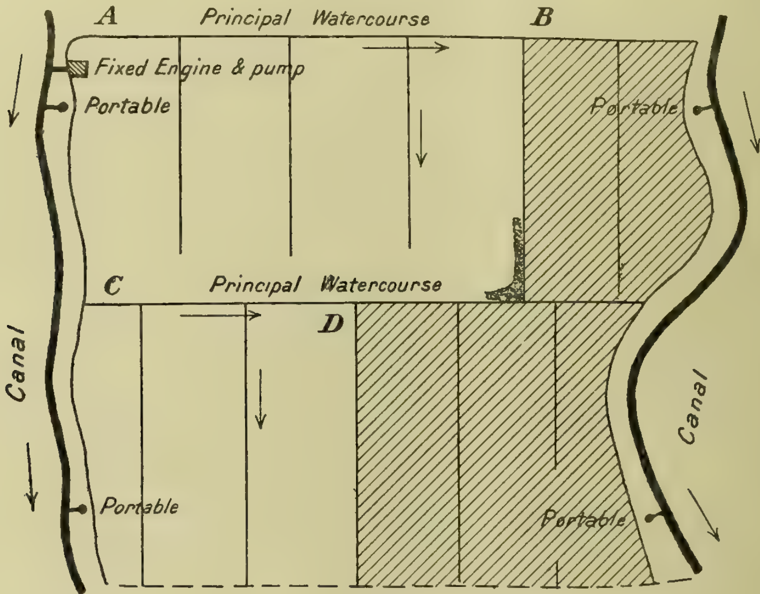



FIG. 30.

pumps to four pumps, one of 20 h.p., one of 16, and two of 12 h.p. We should have acted wisely if we had kept to seven.

Any way we worked these four pumps by a current of 1400–1700 volts, and in seventeen years we have not had a single accident. We lift the water 2·5 metres.

It costs us £·10 per acre per watering. This figure includes interest at 5 per cent. and sinking fund of the electric plant, pumps, and buildings, and all expenses of fuel, establishment, and maintenance. It does not include interest on the central station in the factory.

The electric wires go to a length of 8 kilometres for each pump; with 8 pumps they would have gone half that distance.

Our machinery was put up seventeen years ago. Such improvements have been introduced of recent years that we should now have no fear of accidents and should multiply small pumps if we had to do it again."

77. **The Ibrahimia Canal.**—The Ibrahimia Canal takes off from above the Assiut Barrage and is not only the largest canal in Egypt, but

possibly in the world. It was originally designed and constructed by Baghat Pasha, and opened in 1873.

Before the construction of the Assiut Barrage, the canal took out of the Nile without any regulating work on either the Nile or the canal head, and the silt clearance of the canal was a matter of very serious import, both on account of the discharge and the money expenditure. To reduce the quantity of silt deposit, Sir Hanbury Brown, the Inspector of Irrigation of the Fourth Circle, began in 1886 a series of stone spurs opposite each other and 250 metres apart. Their action was very beneficial, and they were continued until by 1898 the canal was spurred from the head to the 56th kilometre. The following table gives the total expenditure on the work, representing a sum of £44,000.

Table 203.—Cost of Ibrahimia Canal Spurs.

| Year. | Number of Pairs of Spurs made. | Expenditure in £ | | | Totals. £ |
|---|---|---|---|---|---|
| | | on New Spurs. | on Repairs and Remodelling. | on Revetment of Railway Bank. | |
| 1886 | 12 | 2,172 | ... | ... | 2,172 |
| 1887 | 14 | 2,290 | 96 | ... | 2,386 |
| 1888 | 23 | 3,747 | 560 | 1,025 | 5,332 |
| 1889 | 31 | 4,366 | 148 | 558 | 5,072 |
| 1890 | 26 | 4,696 | 80 | 710 | 5,486 |
| 1891 | 32 | 2,507 | 295 | 484 | 3,286 |
| 1892 | 26 | 5,191 | 303 | 274 | 5,768 |
| 1893 | 3 | 1,396 | 724 | 35 | 2,155 |
| 1894 | 9 | 1,828 | 847 | 646 | 3,317 |
| 1895 | 14 | 1,938 | 361 | 359 | 2,658 |
| 1896 | 26 | 1,865 | ... | 125 | 1,990 |
| 1897 | ... | ... | 2,400 | 198 | 2,598 |
| 1898 | ... | ... | 1,808 | ... | 1,808 |
| 1899 | ... | ... | 56 | 15 | 71 |
| | 216 | 31,996 | 7,678 | 4,429 | 44,099 |

The following table shows the amount of silt clearance since 1881. In 1902 the Assiut Barrage on the Nile was completed, and immediately the cube of silt clearance fell.

TABLE 204.—QUANTITIES AND COST OF IBRAHIMIA CANAL SILT CLEARANCE.

| Year. | Minimum Aswan Gauge. | Minimum Assiut Gauge. | Quantity dredged, in cubic metres, | | | Cost. £. |
|---|---|---|---|---|---|---|
| | | | in Canal. | in River. | Total. | |
| 1881 | 85·00 | ... | 428,000 | ... | 428,000 | |
| 1882 | 84·45 | ... | 728,000 | ... | 728,000 | |
| 1883 | 85·04 | 44·98 | 990,000 | ... | 990,000 | |
| 1884 | 85·37 | 45·40 | 1,147,000 | ... | 1,147,000 | 35,000 |
| 1885 | 84·66 | 44·80 | 787,000 | ... | 787,000 | 36,000 |
| 1886 | 84·94 | 45·14 | 461,000 | .. | 461,000 | 24,000 |
| 1887 | 84·97 | 45·26 | 523,000 | ... | 523,000 | 26,000 |
| 1888 | 84·92 | 44·97 | 447,000 | ... | 447,000 | 17,000 |
| 1889 | 84·40 | 44·50 | 629,000 | ... | 629,000 | 23,000 |
| 1890 | 84·40 | 44·43 | 493,000 | ... | 493,000 | 18,000 |
| 1891 | 84·79 | 44·76 | 836,000 | ... | 836,000 | 30,000 |
| 1892 | 84·36 | 44·54 | 413,000 | ... | 413,000 | 16,000 |
| 1893 | 85·35 | 45·18 | 372,000 | ... | 372,000 | 14,000 |
| 1894 | 85·06 | 44·93 | 448,000 | ... | 448,000 | 17,000 |
| 1895 | 85·78 | 45·46 | 351,000 | ... | 351,000 | 13,000 |
| 1896 | 85·49 | 45·26 | 300,000 | ... | 300,000 | 11,000 |
| 1897 | 85·62 | 45·59 | 214,000 | ... | 214,000 | 8,000 |
| 1898 | 84·74 | 44·82 | 248,000 | ... | 248,000 | 9,000 |
| 1899 | 85·15 | 45·32 | 129,000 | ... | 129,000 | 5,000 |
| 1900 | 84·07 | 44·80 | 202,000 | 67,000 | 269,000 | 10,000 |
| 1901 | 84·54 | 44·96 | 312,000 | 147,000 | 460,000 | 16,000 |
| 1902 | 84·42 | 46·16 | 108,000 | ... | 108,000 | 7,000 |
| 1903 | 84·34 | 46·53 | 100,000 | ... | 100,000 | 9,000 |
| 1904 | 84·80 | 46·73 | 100,000 | .. | 100,000 | 7,000 |
| 1905 | 84·40 | 46·95 | 94,000 | ... | 94,000 | 6,000 |
| 1906 | 84·50 | 47·10 | 89,000 | ... | 89,000 | 6,000 |
| 1907 | 84·84 | 47·00 | 106,000 | ... | 106,000 | 7,000 |
| 1908 | 84·50 | 46·84 | 23,000 | 27,000 | 50,000 | 3,400 |
| 1909 | 85·00 | 47·27 | 50,000 | ... | 50,000 | 3,400 |
| 1910 | 84·89 | 47·10 | 12,000 | 38,000 | 50,000 | 3,400 |
| 1911 | 85·00 | 47·15 | 36,000 | 14,000 | 50,000 | 3,400 |
| 1912 | 84·80 | 46·95 | 20,000 | 30,000 | 50,000 | 3,400 |

This question of silt deposit will be further considered in CHAPTER IX.

We now give a description of the Ibrahimia Canal and its principal works, kindly written by Mr G. T. Brooke, Inspector of the Assiut Barrage Circle, and Mr H. Molesworth, Inspector of the Fourth Circle, as a good example of a perennial canal.

"*Assiut Barrage Circle.*

The Ibrahimia Canal from the head to Hafez regulator, 93 kilometres.

The Yusufi Canal from the head to Balansura, 108 kilometres.

From the head to the Deirut regulator, 62 kilometres.

From the Deirut to Hafez regulator, 31 kilometres.

*Discharges.*—The maximum recorded discharge at the head in recent years is

that of the 22nd September 1908—729 cubic metres per second, at R.L. 52·47. The recognised H.F.L. at Deirut in the canal is R.L. 47.

The summer discharge drops as low as 135 cubic metres a second at the head, and the level held at Deirut during summer is 45·20.

The bed is now dredged to R.L. 43·50 at the head with a 4-centimetre/kilometre slope, the R.L. of the bed at kilometre 60·4 (Deirut) being considered as 41·04.

The works on the canal comprise

| | | |
|---|---|---|
| The Head regulator | | |
| The Deirut ,, | | |
| The Hafez ,, | (under Fourth Circle). | |
| The Hawatka road bridge | (under construction). | |
| The Manfalut ,, | ,, | (completed). |
| The Beni Korra | ,, | ,, |
| The Nazali Ganub | ,, | ,, |

The above four are steel pile and wood-decked bridges designed to carry a 20-ton ploughing engine. Each bridge is 5 metres wide, and has an opening swing span giving a clear water-way of 9 metres.

The Head regulator is situated some 400 metres back from the river and has floor at R.L. 43·25—nine openings, 5 metres each, fitted with double grooves down to floor level and two gates, 3·5 metres high each, to each vent.

The maximum flood level in the canal was, when the head work was designed, taken to be R.L. 53·00 with R.L. 53·95 in the river.

The lock is 9 metres wide and 50·00 metres long between mitre posts.

*Deirut Regulators.*—Little being known about these regulators, 5-inch bore holes were sunk, two in each pier, and also round the abutment and lock during closure 1911–12, and subsequently grouted with cement. The foundation was uniformly fine sand, and the pressure due to the grout while still liquid was calculated to be 1·85 kilograms per square centimetre when grouting from the level of the roadway. Runs occurred from only two holes into one hole adjacent to each one in the Ibrahimia regulator—in the Yusufi regulator no runs occurred so that the cement could be traced in any adjacent hole; the two holes took double the amount of cement that they should have to merely fill the bores.

The old three-opening head to the Deirutia Canal has been made to serve as the heads for the Badraman Canal, which now feeds from the eastern opening—the central opening being closed.

The regulation on the Ibrahimia and Yusufi regulators is by means of iron gates—three to each vent—the middle set of the Yusufi gates sliding in grooves which go down to floor level.

The escape is also provided with iron regulating gates—two in each vent.

The escape lock has been abolished and divided into two openings similar to the original five—thus making seven openings in all. Regulation on the Delgawi feeder, Sahilia Canal, Deirutia and Badraman Canals is by horizontal timbers.

Other works on the Ibrahimia Canal are:—

Kilometre 3·5—a syphon of 2 × 1·40 metres diameter bent pipes with screw regulating doors; for topping up Hod Walidia from Hod Mallah.

Kilometre 8·5, east bank—4 metres wide subsidiary feeder to the Beni Hussein Canal.

Kilometre 8, west bank—4 × 3 metres wide feeder to Hod Masra.

Kilometre 7·7, west bank—3 metres wide escape from Hod Mallah.

Also small feeder heads into the hods at kilometres 24·5, 29, 38·5, 47, and 56 —west bank; 45·5 (head of Masara Canal) and kilometre 55—east bank.

The canal is spurred all the way from its head to kilometre 55, the spurs being in pairs opposite each other and 250 metres apart.

From kilometre 55 to kilometre 60·4 (Deirut) the east bank is completely revetted on the railway side.

Since the Assiut Barrage has come into operation and the theoretical bed raised to R.L. 43·50 at head, the amount of silt dredged has lain in the first 5 kilometres and averages in quantity some 40,000 cubic metres only.

*From Deirut to Hafez Regulator.*—Bed width, 49 metres; bed slope, 6½ centimetres per kilometre; flood level at Deirut 45·50, slope 6 centimetres per kilometre, giving a discharge of 185 cubic metres per second.

27·5 kilometres below Deirut is an old regulator and aqueduct known as Um Tissa—on which the afflux in flood is some 60 centimetres. This old work is now used as a road bridge and also by the Upper Egypt auxiliary railways.

The average discharges are:—

| | | | | |
|---|---|---|---|---|
| Ibrahimia above Deirut | 127 to 162 | cubic metres | per second | in summer. |
| ,, ,, ,, | up to 800 | ,, | ,, | in flood. |
| ,, ,, ,, | 185 | ,, | ,, | in winter. |
| Ibrahimia below Deirut | 75 to 92 | ,, | ,, | in summer. |
| ,, ,, ,, | 185 | ,, | ,, | in flood. |
| ,, ,, ,, | 115 | ,, | ,, | in winter. |
| Yusufi | 40 to 46* | ,, | ,, | in summer. |
| ,, (maximum flood level 46·50) | 300 | ,, | ,, | in flood. |
| ,, | 46† | ,, | ,, | in winter." |

"*Fourth Circle of Irrigation.*

The Ibrahimia Canal from Hafez regulator, kilometre 93, to the tail, kilometre 318.

The Yusufi Canal from Balansura, kilometre 108, to tail, kilometre 339.

The Ibrahimia Canal below Deirut has a bed width of 49 metres; and a water slope of 0·066 metre per kilometre; the bed slope being the same. The bed level is 41·28 and the H.F.L. 45·50, depth of water 4·22 metres. The canal is designed to give 30 cubic metres per acre per twenty-four hours, and the recorded discharges show a discharge of over 16 million cubic metres per day, or 185 cubic metres per second.

The first regulator below Deirut is the Hafez regulator at kilometre 92·700 from the canal head at Assiut.

There are seven openings of 3·00 metres each. Floor level is R.L. 38·00, H.F.L. 42·90, and 42·40 upstream and downstream.

The bed width below this regulator to Minia is 35·50 metres at a level of 39·16

* The Yusufi gets a good deal of drainage water from the Fourth Circle and openings in the first 10 kilometres of the Ibrahimia Canal on its west bank.

† The Deirut Escape, now that the lock (which used to be fully opened in flood when necessary) is abolished, will not now discharge more than the Yusufi: the discharging power, of course, depends on the level of the river at Deirut.

below Hafez and a bed slope of 0·066 metre per kilometre, the water slope being the same.

The next regulator is at kilometre 126·320 (Minia), where there are five openings of 3·00 metres each. The lock has been transformed into two vents and used for regulation. The floor level is 35·45, H.F.L. 40·80, and 39·80 upstream and downstream.

The bed width below Minia is 35·25, and bed level 36·85, with a bed slope of 0·08 metre per kilometre, the water slope being the same.

Next comes the Matai regulator at kilometre 166·500, with six openings of 2·50 metres each, R.L. of floor 33·00, H.F.L. 36·90 and 36·55 upstream and downstream. The bed width below this is 32·00 metre, and level 33·66 R.L. The bed slope is 0·08, and the water slope the same.

Next is the Maghagha regulator at kilometre 193·900, with five openings of 2·50 and two of 3·50 (two vents of transformed lock); the H.F.Ls. are 34·80 and 33·90 upstream and downstream, and the floor level is 31·00 downstream; the bed width is 29·00 metres and the bed level 31·48 with bed and water slopes of 0·010 metre per kilometre.

The Sharahna regulator at kilometre 218 has four openings of 3 metres each, with H.F.Ls. of 32·00 and 31·85 upstream and downstream; floor level of 29·20, bed and water slopes of 0·08 metre per kilometre and a bed width of 20 metres with a level of 29·10.

Gonedi regulator at Beni Suef at kilometre 251 has four openings of 3·00 metres each and a floor level of 25·96, H.F.Ls. of 29·20 and 29·00 upstream and downstream, and bed width of 15·50 metres at a level of 25·96, bed and water slopes of 0·08 metre per kilometre.

At kilometre 264 is Ashment regulator, with two openings of 3 metres each and a floor level of 24·11; H.F.Ls. of 28·24 and 27·82 upstream and downstream; the bed and water slopes from here on to below Kafr Ammar are 0·06 metre per kilometre; the bed width is 9·00 metres, having been reduced at Bouche to 11·00 metres at the intake of the Koshesha Canal; the bed level is 24·11.

At kilometre 279 is the Koshesha syphon, under the Magrur Koshesha; this consists of three pipes of 2·00 metres diameter; the H.F.Ls. are 27·57 and 27·00 upstream and downstream.

At kilometre 282 is the Wasta regulator, with one opening of 2·50 metres, a floor level of 23·74 and H.F.Ls. of 26·96 and 26·50; the bed level downstream is 23·94 and the bed width 5·50 metres.

At kilometre 295 is the Girza regulator, with one opening of 2·50 and H.F.Ls. of 25·25 and 25·14; a bed width downstream of 3·50 at a level of 23·03.

At kilometre 303 is the Kafr Ammar regulator (converted), with two openings of 2·75 metres each and a floor level of 20·73; H.F.Ls. of 24·82 and 24·03 upstream and downstream; a bed width of 3 metres at a level of 22·53.

At kilometre 306 is the Mit El-Kayed regulator, with one opening of 2·50 and H.F.Ls. of 24·43 and 24·07 and a floor level of 21·83.

The tail escape comes at kilometre 318, the total length of the Ibrahimia Canal from Assiut. The escape has one opening and discharges into the Messenda drain; the H.F.L. is 23·25 and bed width 3·00.

The escapes are at Massara, at Samalut, at Sharahna, at Beni Suef (Saaida escape), at Ashment (Magnuna), and at Wasta (the Zawia Escape).

The works on the Bahr Yusuf are Nazlet Abid, Sakula, and Mazura. The first two have twenty openings each of 3 metres, and the last-named has twenty-five openings of 3 metres each. All have locks of 6·00 metres width and 24·30 metres length.

The following are the details of the regulators:—

| Regulators. | Floor. R.L. | Springing. R.L. | H.F.L.—R.L. | |
|---|---|---|---|---|
| | | | Upstream. | Downstream. |
| Nazlet Abid . . | 35·50 | 41·50 | 40·80 | 40·35 |
| Sakula . . . | 28·35 | 34·75 | 34·70 | 34·00 |
| Mazura . . . | 23·92 | ... | 30·80 | 30,00 |

The distance from Nazlet Abid to Sakula is 102·125 kilometres, from Sakula to Mazura is 40 kilometres, and from Mazura to Lahun is 67 kilometres.

The Abu Bahr escape has twenty-five openings of 3 metres each. All these works are fitted with winches and iron gates.

The Giza Canal head and the Hagar Koshesha feeder are the two remaining works of importance to the Fourth Circle.

The southern portion of the Minia Province is served by the Moheit drain, which enters the circle at Kabkab syphon under the Sabakha Canal; this follows the old basin Moheit bank, and reaches the old Etsa feeder, where, when levels allow, the drainage is passed into the Nile.

At Etsa on the north side of the drain, and to the east of the Ibrahimia Canal and State railway, a pumping station has been built to lift the drainage when necessary and pass it round the tail regulator of the drain into the Nile.

The installation consists of four 40-inch pumps driven by four vertical direct-acting engines of 165 I.H.P. each, and six boilers with a working pressure of 125 lbs. per square inch.

The pumps are capable of delivering 2 cubic metres per second with a lift of 4·50 metres and 115 revolutions per minute, and a coal consumption of 1·85 lbs. per h.p. per hour.

The installation cost £45,137. It is in operation from ten days to one month each year, on the average.

In very low floods with an early drop the station need not work.

It is the only station in connection with drainage built by the Conversion works.

So long as the D.S. level at Sakula does not exceed R.L. 32·00 the drainage of the southern part of Minia Province can be passed on (if the Nile is high) through the Etsa regulator on the drain and discharged into the Yusufi at Abu Rahib downstream of Sakula. The drainage can also pass on when downstream of Sakula is above R.L. 32·00, and find its way down the western Moheit drain to Talt, where it joins the Absug drain, into which also falls the Central Moheit draining the province in the middle of its northern half.

The Absug drain can discharge into the Nile or Yusufi, at Sharahna (north of Feshn), or below Mazura as levels allow; but this system is not provided with a pumping station and is not connected with the system in Beni Suef Province. For this reason careful manipulation of the levels downstream Mazura is required; but as the discharge of the Yusufi basins cannot be retarded indefinitely, the level

downstream Mazura must rise, and, if the Nile is simultaneously high, no outlet at Sharahna is available; flooding out of the Fant depression is therefore unavoidable under these circumstances for so long as the Yusufi and Nile levels remain high.

The bed width of the Moheit drain above the Etsa regulator is 17·50 metres, and below it 7·50 metres.

The main drain in Beni Suef Province is also known as the Moheit drain, following as it does the line of the old Moheit bank.

Part of the drainage of Hod Sultani finds its way by a syphon under the Sultani Canal into the head of the Moheit drain. West of Beni Suef there is a regulator on the drain, called Damushia regulator, by which drainage can be diverted to the Nile, passing by the Bahabshin syphon under the Ibrahimia Canal and into the Saaida escape channel south of Beni Suef town.

The drain follows the Moheit bank at the edge of what is known as the old perennial area to the Salibet Dandil, where it enters the Hod Koshesha. It crosses the Magrur Koshesha by a syphon 300 metres in length, consisting of five pipes of 2·00 metres diameter; it then runs parallel with the Giza Canal and has an escape to the Nile east from Tahma syphon at Messenda to the north of Ayat. At Tahma it syphons under the Giza Canal and continues northwards. The maximum bed width of the Moheit drain in Beni Suef Province is 15 metres. Except for that portion of the year when both the Yusufi and the Nile are high the drainage of the Moheit drain is good."

Reference should now be made to paragraph 73, which contains a report by Mr J. B. Ireland on the perennial works recently constructed on the Ibrahimia Canal.

We recapitulate here from paragraph 65 the fact that the Ibrahimia Canal commands 618,000 acres, while there are 304,000 acres in the Fayum, making a total of 922,000 acres of perennial irrigation on the Ibrahimia Canal, in addition to the 138,000 acres of basin irrigation along the edge of the desert.

An excellent description of the works carried out in the converted basins, with full details and drawings, is given by M. Edmond Béchara (now directing the Irrigation Works in Mesopotamia) in his book *Irrigation pérenne des bassins de la moyenne Egypte.* In CHAPTER X. will be found some plates of drawings from this book.

78. **The Fayum.**—The Fayum Province is the dry bed of the Lake Mœris of the ancients. Its irrigation was thus described in the second edition of this work:—

"The Bahr Yusuf, which receives its supply from the Ibrahimia Canal at Deirût, traverses the Assiut, Minia, and Beni Suef Provinces for 316 kilometres, and finally leaves the valley of the Nile at Lahun. After a further course of 22 kilometres it flows through the town of Medinet el Fayum, the ancient Arsinoë. Near this town it is divided into some fourteen canals, which irrigate the Province of the Fayum, the only oasis in Egypt in direct communication with the Nile. Three small canals, however, one on the right and two on the left, had taken off about midway between

Lahun and Medinet. The Fayum is a veritable oasis, surrounded on all sides by desert and connected with the valley of the Nile by the thin strip of cultivation along the Bahr Yusuf.

The depression in the Libyan hills at Lahun is about 6 kilometres wide, and across this depression there runs a very ancient bank of great height and width, which was revetted with masonry on its eastern slope in 1835. This bank separates the Fayum from the Koshêsha basin of the Beni Suef Province. The following figure gives the mean section of the bank, and shows the reduced level of the country and of the water in the Koshêsha basin during flood. Near the village of Lahun the bank is pierced by a new regulator with two openings of 3 metres each, and one opening of 4 metres. Below it is Mohamed Ali's old regulator, which has gradually been undermined. The mean slope of the Bahr Yusuf from Lahun to Medinet is $\frac{1}{16,000}$. For the first 12 kilometres the Bahr flows within an earthen channel on a slope of $\frac{1}{24,000}$; in the next 3 kilometres it is broken up into a series of rapids with a limestone bed. For the rest of its course, up to Medinet, it again flows within earthen banks on a slope of $\frac{1}{24,000}$. Up to the 12th kilometre the Bahr has followed its natural channel; after this point, and if left to itself, it would have followed one of the three deep ravines on the right, and thus escaped to the Birket el Kurûn, or lake, to the north of the Fayum. To keep up the level

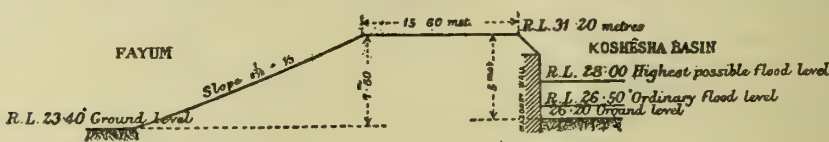



FIG. 31.

of water for irrigation, however, two of these three deep ravines were banked across by massive earthen embankments, while at the third an old escape head was built up. By turning the Bahr Yusuf over the limestone bars it has been kept on the watershed and rendered capable of feeding all the canals of the province. The maintenance of all these embankments in first-class order is a matter of the greatest importance. A breach would be attended with the most disastrous consequences. Breaches *are* possible, as Linant Pasha describes the carrying away of one of these embankments in 1820.

Fig. 32 gives the longitudinal section of the country from Lahun to the lake. Up to Medinet, a distance of 22 kilometres, the slope is $\frac{1}{11,000}$, the same as the general slope of Upper Egypt. From kilometre 22 to kilometre 36 the slope is $\frac{1}{1200}$. We have now reached the level of the Mediterranean. For the remaining 8 kilometres the slope is $\frac{1}{180}$. The water surface of the lake itself is over 40 metres below the Mediterranean. This longitudinal section, which is a type one of the province, shows clearly that the flat lands of the province near Medinet el Fayum were formed by basin irrigation or by deposits above water-level, while the steep slopes were deposited under water. This was in the old days when the ancient Lake Mœris covered everything except the flat lands round Medinet el Fayum. The same features are met with in the Delta when we compare the slope of the land above sea-level with that below sea-level along the edge of the Mediterranean. From discharge observations near the head of the Bahr Yusuf a gauge of 22·33 metres R.L. in summer gives a sectional area of 147·8 metres, a

slope of $\frac{1}{48,000}$, a mean velocity of ·12 metre per second, and a discharge of 17·5

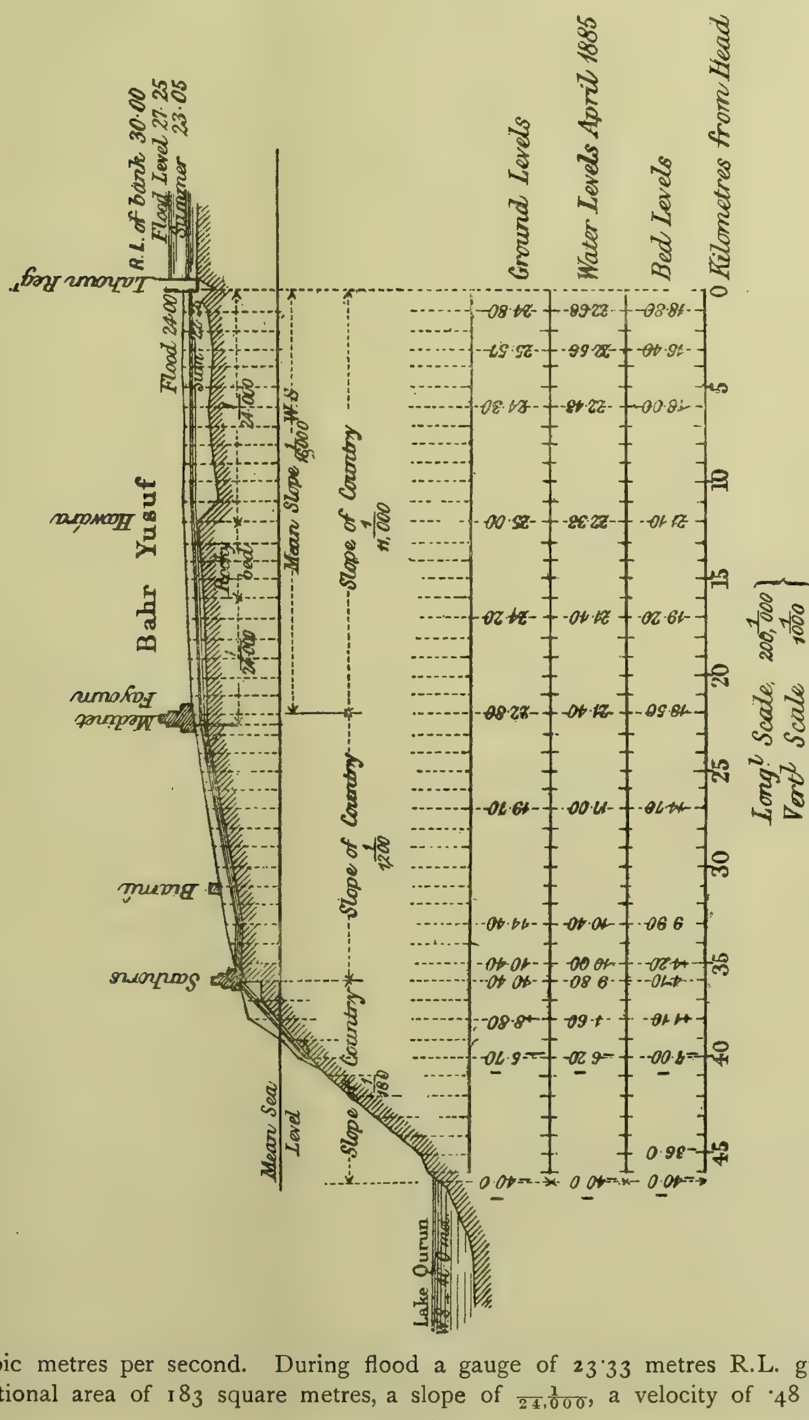


FIG. 32.—Longitudinal Section of the Fayum.

cubic metres per second. During flood a gauge of 23·33 metres R.L. gives a sectional area of 183 square metres, a slope of $\frac{1}{24,000}$, a velocity of ·48 metre

per second, and a discharge of 89 cubic metres per second. The bed width is about 25 metres roughly.

On referring to the plan it will be seen that the country is cut up by deep ravines, some of which are 100 metres in width and 15 metres in depth; the two main ones are known as the Bats and Wadi el Nezla, and both tail into the Birket el Kurûn. Indeed, many of the canals are more or less ravines. It is quite a common feature in the Fayum to see wheels lifting water by water power; while all the canals are studded with corn mills worked by turbines (panchakkis) of a pattern introduced from India some thirty years ago."

The following report on the Fayum Province has been kindly sent us by the Inspector, Hassan Wassif Bey.

"The area of the Fayum Province is classified as follows:—

| | Acres. | Total. Acres. |
|---|---|---|
| Land taxed permanently (from £·13 to £1·570) | 253,836 | |
| Land taxed temporarily (from £·20 to £1·070) | 70,773 | |
| Total of land taxed permanently and temporarily | | 324,609 |
| Land untaxed and uncultivated | 15,172 | |
| Government land (rented) | 6,899 | |
| Government land (not rented and not cultivated) | 51,479 | |
| Public Utility land | 14,941 | |
| | | 88,491 |
| Total area of province | | 413,100 |

The cultivated area amounts to 306,000 acres.

*Discharges: Supply entering the Fayum.*

The New Hassan Wassif Canal, which takes its supply from the Yusufi upstream of Lahun regulator, was dug to feed the two main canals of Gharak and Nazla, which formerly were fed by the Yusufi below Lahun regulator, and the average total discharge of this canal and the Yusufi below Lahun amounts to about 3,000,000 cubic metres per day during summer, 8,640,000 cubic metres per day during flood, and 5,000,000 during winter.

The area under irrigation in the three seasons are 87,000 acres in summer, and 306,000 acres in flood and winter. The duty in summer is therefore 2500 acres per cubic metre per second, in flood it is 3060 acres per cubic metre per second, and in winter 5300 acres per cubic metre per second.

Twenty per cent. of the supply entering the province during the whole year finds its way into the lake. During the summer only 12 per cent. of the supply enters the lake, and during the flood 14 per cent. In consequence of this the highest level of the lake recorded in 1907 was 44·25, and in 1912 it was 44·19—a rise of 6 centimetres only. The level of the lake begins to fall at the beginning of April, and reaches its lowest level at the end of August—the total fall being about 75 centimetres yearly.

*Summer Rotations.*

These rotations usually begin in the middle of April and end on 15th August. The canals are usually divided into two divisions taking ten days' supply alternately.

*Flood Rotations.*

These usually begin in the first week of September, and end in the middle of December, the canals receiving alternately seven days' high and seven days' low supply.

In the Fayum to-day nearly all the canals have been remodelled and have been given sections large enough for the flood irrigation of the whole areas dependent on them, and have been provided with regulators and masonry Nasbas where necessary for the accurate distribution among the smaller channels, the areas dependent on which are calculated from the provincial lists and survey maps. The effect of this, together with careful regulation, is to reduce waste of water to a minimum, and to cause an increased area of land to come under cultivation.

In fact the regularly cultivated area has now spread as far as the edge of the lake except in some places.

In spite of the increased supply of water necessitated by this extension, the lake has not shown any tendency to rise above its former level, which is undoubtedly due to better control of supply and prevention of wastage.

The value of the land thus reclaimed is in some cases as much as £80 per acre, and will probably increase as the quality of the land improves in time with careful cultivation.

The Fayum Light Railways Company owns a network of agricultural lines radiating from Medinet el Fayum; but their present arrangement is incomplete, and if some of the shorter branches were linked together and an extension made through the rich central plateau of the province, considerable benefit would be reaped by the cultivators and the Company.

Large quantities of fish are caught in the Lake Kurûn, but there are no proper means of transport over the 10 or 15 kilometres from the fishing centres on the shore to the nearest railway station.

A line connecting these points would be of the greatest advantage to the fishing industry, and would do much towards keeping it in a thriving condition.

At present the fish is entirely transported by pack animals.

TABLE 205.—DETAILS OF EXISTING WORKS IN FAYUM PROVINCE.

| Name of Work. | Details. | Remarks. |
|---|---|---|
| | kilometres. | |
| Banks | 5 | |
| Perennial canals | 1567 | Of which 179 kilometres are main canals, and 1388 kilometres are minor. |
| „ drains | 661 | |
| | No. | |
| „ escapes | 1 | |
| „ regulators | 27 | |
| „ syphons | 21 | |
| Head sluices for canals | 57 | |
| Masonry distributors (Nasbas) | 191 | |
| Aqueducts | 14 | |

There is also a very large number of masonry weirs and falls on the canals and drains which are necessitated by the comparatively great slope of the country.

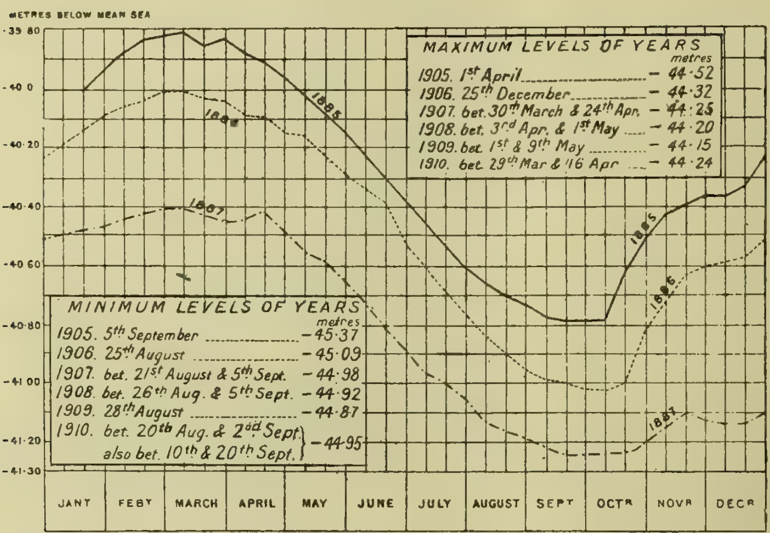



FIG. 33.—Lake Kurûn—Gauge Diagram.

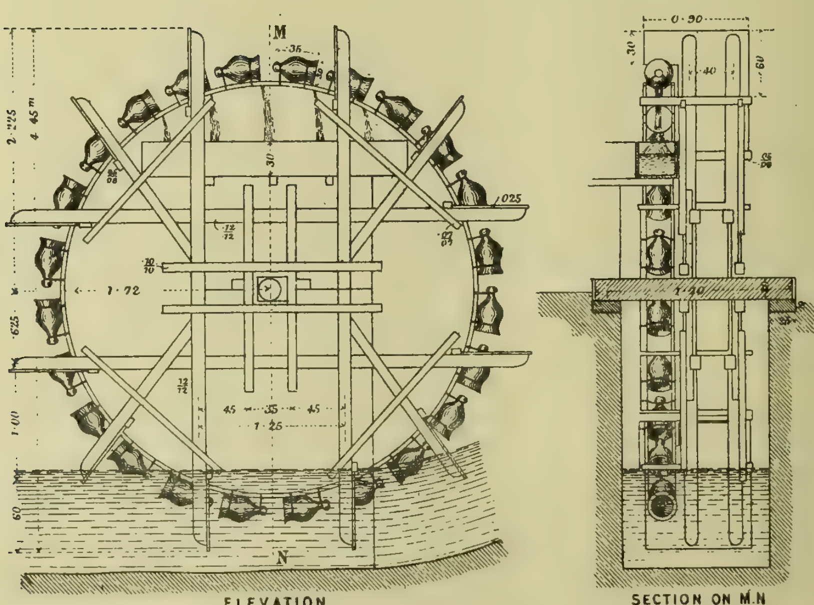



FIG. 33A.—Undershot Wheel in Fayum for raising Water.

TABLE 206.—DETAILS OF WATER-LIFTING MACHINES IN FAYUM PROVINCE.

| Fixed Engines. | | | | | | Portable Engines. | | | | | | Water Wheels (Sakias). | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| On Canals. | | On the Bahr Yusuf. | | Total. | | On Canals. | | On the Bahr Yusuf. | | Total. | | On Canals. | On the Bahr Yusuf. | Total. |
| No. | H.P. | No. | H.P. | No. | H.P. | No. | H.P. | No. | H.P. | No. | H.P. | No. | No. | No. |
| 2 | 32 | 1 | 12 | 3 | 44 | 19 | 158 | 6 | 58 | 25 | 216 | 627 | 155 | 782 |

*Note.*—Of the 627 water-wheels on canals there are 77 that are driven by water power, and of the 155 on the Bahr Yusuf there are 10 water-wheels of this sort known as 'Sakias Hadîr.'

In addition to the above there are two turbines, one on Bahr Seila and the other on Bats Tamia. The former is used to work a flour mill, and the latter for a cotton-ginning factory and a flour mill.

There are also 267 flour mills worked by water-power on the canals and drains throughout the province."



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# LOWER EGYPT AND THE FAYÛM



Willcocks & Craig, Egyptian Irrigation, E & F. Spon Ltd.

Plate 28.


MAP OF UPPER EGYPT
SCALE 1:500,000
Kilometres
Kilometres
REFERENCE
Mudiria Towns
Markaz Towns
State Railways
ABU QIRQAS
El Roda
MELLAWI
Dashlut
Sanabu
El Qusia
MANFALUT
ABNUB
Beni Rizah
El Hawatka
Beni Adi
ASSIUT
Dronka
Shotb
El Matia
Musha
Baqur
Rifa
ABU TIG
Beni Samei
El Nokheila
EL BADARI
El Eqal Bahari
El Zarabi
El Deweir
Deir el Canadla
El Ghanaim
Tema
Mishta
Shattura
Nazlet Emara
Banga
TAHTA
El Sawama
Enaibes
Nazza
Goheina
El Sawama
AKHMIM
SOHAG
Balasfura
El Minsha
Aulad Hamza
Aulad Gobara
GIRGA
El Mansha
BALIANA
El Aosat Sambud
NAGA HAMADI
El Qamrawa
Farshut
QENA
El Gabulau
Silwa
Aqlit
Daraw
ASWAN
1st Cataract
Aswan Dam
Shellal


Survey Dept, Egypt 1913 (417 380)

EGYPT 1:250000.

Willcocks & Craig, Egyptian Irrigation, E. & F. Spon Ltd.

# FAYUM

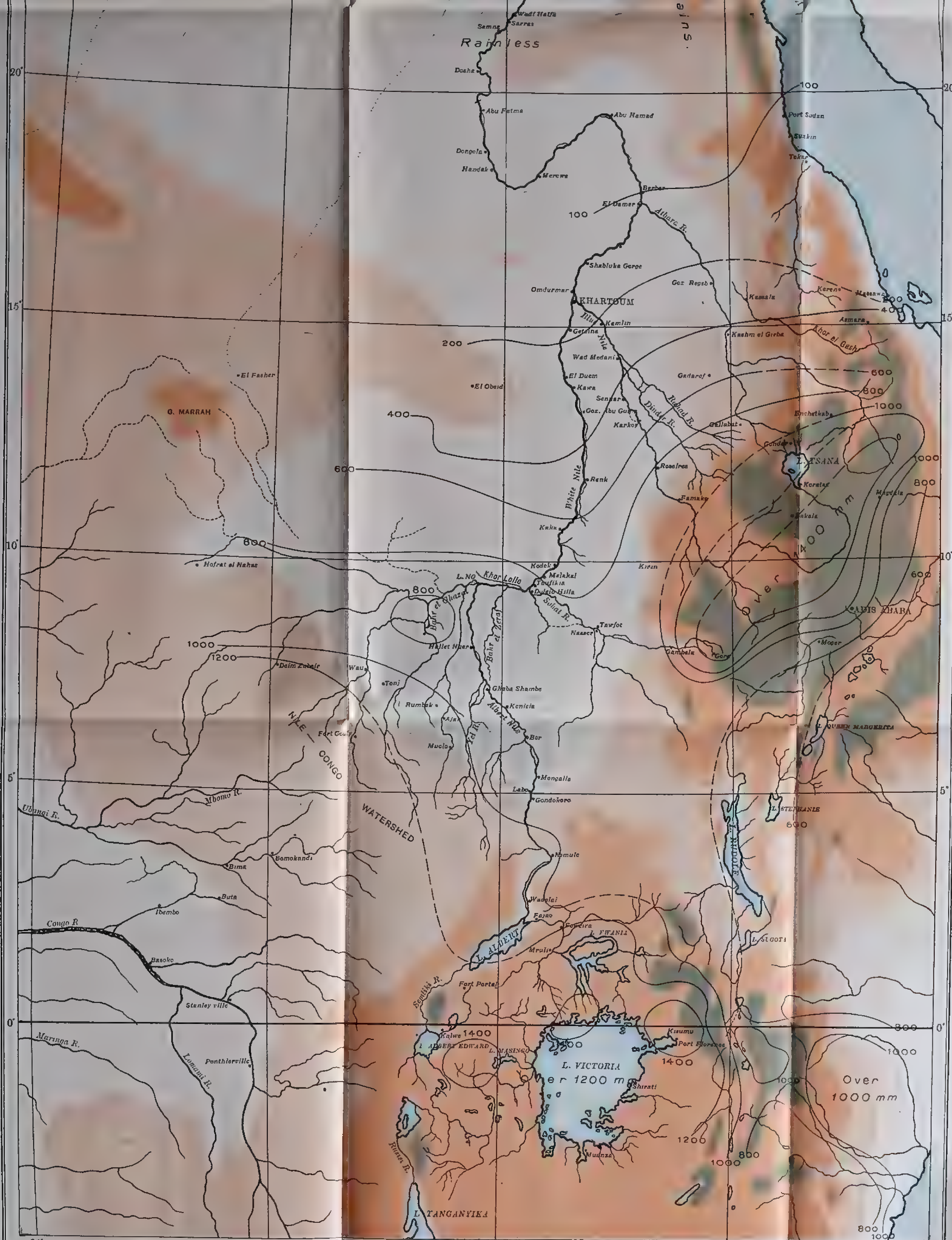
SHEET 3-E.

Plate 33.

# MAP OF NILE VALLEY

WILLCOCKS & CRAIG, EGYPTIAN IRRIGATION, E. & F. SPON Ltd.

PLATE 1




SURVEY DEPT CAIRO 1913 (417 366)

Scale 1 : 7.500,000 or 1 inch = 118 statute miles

MILES 50 0 100 200 300 MILES